U.S. DEPARTMENT OF COMMERCE
National Technical Informatien Service

PB-264 452

# Urban Runoff Pollution Control Technology Overview

Municipal Environmental Research Lab, Edison, N J

Mar 77

## TECHNICAL REPORT DATA

*(Please read Instructions on the reverse before completing)*

1. REPORT NO.
EPA-600/2-77-047

2.

3. RECIPIENT'S ACCESSION NO.

4. TITLE AND SUBTITLE
URBAN RUNOFF POLLUTION CONTROL TECHNOLOGY OVERVIEW

5. REPORT DATE
March 1977 (Issuing Date)

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
Richard Field, Anthony N. Tafuri, Hugh E. Masters

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Storm and Combined Sewer Section
Wastewater Research Division
Municipal Environmental Research Laboratory
Edison, New Jersey 08817

10. PROGRAM ELEMENT NO.
1BC611

11. CONTRACT/GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS
Municipal Environmental Research Laboratory--Cin.,OH
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

13. TYPE OF REPORT AND PERIOD COVERED
Final; In-house Report FY'77

14. SPONSORING AGENCY CODE
EPA/600/14

15. SUPPLEMENTARY NOTES
Supplement to EPA-600/2-76-095, "Urban Runoff Pollution Control Program Overview: FY'76" P.O. Richard Field, Chief, Storm & Combined Sewer Section, (201)321-6674, 8-340-6674

16. ABSTRACT

This Overview describes the major elements of the Urban Runoff Pollution Control Program. Problem Definition, User Assistance Tools, Management Alternatives and Technology Transfer are covered, including some of the highlights of the Program's future direction and products from over 150 of its research projects. References are cited for completed Program reports, ongoing Program projects, and in-house documents.

Capital cost comparisons for storm and combined sewer control/treatment are given, along with a specific example of cost-effect solution for urban runoff pollution control by in-line storage in Seattle. In a study done in Des Moines, using a simplified receiving water model, four control alternatives were compared, considering cost and effectiveness in terms of a frequency of D.O. standard violations.

17. KEY WORDS AND DOCUMENT ANALYSIS

| a. DESCRIPTORS | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group |
|---|---|---|
| Water pollution, Waste Treatment, Sewage Treatment, Runoff, Wastewater, Sewage, Overflows--Sewers, Cost effectiveness, Combined Sewers, Surface water runoff, Collection, Sludge, Water Quality, Hydrology | Drainage systems, Water pollution control, Urban runoff pollution/control, Storm runoff, Waste water treatment, Research and development | 13B |

| | | |
|---|---|---|
| 18. DISTRIBUTION STATEMENT<br>RELEASE TO PUBLIC | 19. SECURITY CLASS *(This Report)*<br>UNCLASSIFIED | 21. NO. OF PAGES<br>103 |
| | 20. SECURITY CLASS *(This page)*<br>UNCLASSIFIED | 22. PRICE |

EPA Form 2220-1 (9-73)

☆ U.S. GOVERNMENT PRINTING OFFICE: 1977-757-056/5474 Region No. 5-11

PB 264 452

EPA-600/2-77-047
March 1977

Environmental Protection Technology Series

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

## RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into five series. These five broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The five series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

EPA-600/2-77-047
March 1977

# URBAN RUNOFF POLLUTION CONTROL TECHNOLOGY OVERVIEW

by

Richard Field
Anthony N. Tafuri
Hugh E. Masters
Storm and Combined Sewer Section
Municipal Environmental Research Laboratory (Cincinnati)
Edison, New Jersey 08817

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

1a

# DISCLAIMER

This report has been reviewed by the Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

# FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This report developed for the EPA Office of Air, Land and Water Use, Office of Research and Development "State-of-the-Art Research Seminar Series," on September 28, 1976, constitutes a review of EPA's R&D Program for Urban Runoff Pollution Control. It describes completed work, ongoing work and future work required to abate pollution from wet-weather flows and presents the overall philosophy of approach to this specific problem as far as EPA's R&D Program sees it.

Francis T. Mayo
Director
Municipal Environmental Research
Laboratory

# ABSTRACT

This Overview describes the major elements of the Urban Runoff Pollution Control Program. Problem Definition, User Assistance Tools, Management Alternatives and Technology Transfer are covered, including some of the highlights of the Program's future direction and products from over 150 of its research projects. References are cited for completed Program reports, ongoing Program projects, and in-house documents.

Capital cost comparisons for storm and combined sewer control/treatment are given, along with a specific example of cost-effect solution for urban runoff pollution control by in-line storage in Seattle. In a study done in Des Moines, using a simplified receiving water model, four control alternatives were compared, considering cost and effectiveness in terms of a frequency of D.O. standard violations.

## CONTENTS

Foreword . . . . . . . . . . . . . . . . . . . . . . . . . . . . iii
Abstract . . . . . . . . . . . . . . . . . . . . . . . . . . . . iv
Figures . . . . . . . . . . . . . . . . . . . . . . . . . . . . viii
Tables . . . . . . . . . . . . . . . . . . . . . . . . . . . . . x
Acknowledgments. . . . . . . . . . . . . . . . . . . . . . . . . xi

1. INTRODUCTION. . . . . . . . . . . . . . . . . . . . . . . . . 1

2. PROBLEM DEFINITION. . . . . . . . . . . . . . . . . . . . . . 4

Characterization. . . . . . . . . . . . . . . . . . . . . . . . 4
  Representative Concentrations . . . . . . . . . . . . . . . . 4
  Representative Loads. . . . . . . . . . . . . . . . . . . . . 7
  Potential Impacts . . . . . . . . . . . . . . . . . . . . . . 7
  Receiving Water Quality Impacts . . . . . . . . . . . . . . . 8
  Erosion/Sediment Impacts. . . . . . . . . . . . . . . . . . . 10
  Characterization: Products . . . . . . . . . . . . . . . . . 10
  Nationwide Cost Assessment. . . . . . . . . . . . . . . . . . 10
    Sewer Separation. . . . . . . . . . . . . . . . . . . . . . 10
    High Cost Implied . . . . . . . . . . . . . . . . . . . . . 12
    New R&D Estimates Imply Lower Costs . . . . . . . . . . . . 12
  Solution Methodology. . . . . . . . . . . . . . . . . . . . . 12
    More Accurate Problem Assessment. . . . . . . . . . . . . . 14
    Cost-Effective Approach . . . . . . . . . . . . . . . . . . 14
    Example Solution Methodology. . . . . . . . . . . . . . . . 15
    Overcome Administrative Problems. . . . . . . . . . . . . . 15
    Solution Methodology: Products . . . . . . . . . . . . . . 17

3. USER ASSISTANCE TOOLS . . . . . . . . . . . . . . . . . . . . 20

Instrumentation . . . . . . . . . . . . . . . . . . . . . . . . 20
  Instrumentation: Products. . . . . . . . . . . . . . . . . . 22
Simulation Models . . . . . . . . . . . . . . . . . . . . . . . 22
  Planning/Design Models. . . . . . . . . . . . . . . . . . . . 24
    Level I . . . . . . . . . . . . . . . . . . . . . . . . . . 24
    Level II. . . . . . . . . . . . . . . . . . . . . . . . . . 26
    Level III . . . . . . . . . . . . . . . . . . . . . . . . . 27
    Level IV. . . . . . . . . . . . . . . . . . . . . . . . . . 27
  Operation Models. . . . . . . . . . . . . . . . . . . . . . . 27
  Simulation Models: Products. . . . . . . . . . . . . . . . . 27

## CONTENTS (Continued)

4. MANAGEMENT ALTERNATIVES . . . . . 29

- Land Management . . . . . 29
  - Structural/Semi-Structural Control . . . . . 29
    - On-Site (Upstream) Storage . . . . . 31
    - Porous Pavements . . . . . 32
    - Overland Flow Modification . . . . . 32
    - Solids Separation . . . . . 33
  - Non-Structural . . . . . 33
    - Surface Sanitation . . . . . 33
    - Chemical Use Control . . . . . 34
    - Urban Development Resource Planning . . . . . 36
    - Use of Natural Drainage . . . . . 36
    - Erosion/Sedimentation Control (Non-Structural) . . . . . 37
  - Integrated Benefits . . . . . 37
  - Erosion/Sediment Control: Products . . . . . 37
  - Hydrologic Modification Category Status . . . . . 39
- Collection System Controls . . . . . 39
  - Catch Basins . . . . . 39
  - Sewers . . . . . 41
    - Polymers to Increase Capacity . . . . . 41
    - Infiltration/Inflow . . . . . 41
  - Flow Routing . . . . . 41
  - Regulators and Tide Gates . . . . . 42
    - Swirl and Helical Device Development . . . . . 42
      - Swirl and Helical: Products . . . . . 42
  - Maintenance . . . . . 42
- Storage . . . . . 44
- Treatment . . . . . 47
  - Physical/Chemical Treatment . . . . . 47
  - Land Disposal . . . . . 49
  - Biological Treatment . . . . . 49
  - Disinfection . . . . . 50
  - Treatment Process Performance . . . . . 50
  - Treatment: Products . . . . . 51
- Sludge/Solids . . . . . 51
  - Sludge: Products . . . . . 51
- Integrated Systems . . . . . 53
  - Storage/Treatment . . . . . 53
  - Dual Use, WWF/DWF Facilities . . . . . 53
  - Control/Treatment/Reuse . . . . . 53
  - Integrated Systems: Products . . . . . 55

5. TECHNICAL ASSISTANCE/TECHNOLOGY TRANSFER . . . . . 56

- Significant Documents Completed . . . . . 56
- Significant Documents Anticipated . . . . . 57

6. CAPITAL COSTS COMPARISONS FOR STORM AND COMBINED SEWER CONTROL/TREATMENT . . . . . . . . . . . . . . . . . . . . . . . 58

7. SEATTLE: IN-LINE STORAGE IS COST-EFFECTIVE . . . . . . . . . . 60

Costs . . . . . . . . . . . . . . . . . . . . . . . . . . . . 60
Pollutant Reduction . . . . . . . . . . . . . . . . . . . . . 60
Effectiveness . . . . . . . . . . . . . . . . . . . . . . . . 60

8. DES MOINES: CONTROL COSTS VS. D.O. VIOLATIONS. . . . . . . . . 61

9. CONCLUSION. . . . . . . . . . . . . . . . . . . . . . . . . . . 62

10. REFERENCES AND BIBLIOGRAPHY . . . . . . . . . . . . . . . . . 53

Bibliography of Urban Runoff Control Program Reports. . . . . . 64
Ongoing Urban Runoff Pollution Control Projects ("P" Nos.). . 84
Other Urban Runoff Pollution Control Program References ("R" Nos.) . . . . . . . . . . . . . . . . . . . . . . . . . . . 88

## FIGURES

| Number | | Page |
|---|---|---|
| 1 | EPA Storm and Combined Sewer R&D Program | 2 |
| 2 | Problem Definition | 5 |
| 3 | Representative Strengths of Wastewaters (Flow Weighted Means in mg/l) | 6 |
| 4 | Dry Weather Dissolved Oxygen Concentrations, Wells Street, Milwaukee River, Milwaukee, WI | 9 |
| 5 | Wet Weather Dissolved Oxygen Concentrations, Wells Street, Milwaukee River, Milwaukee, WI | 9 |
| 6 | Dry Weather Fecal Coliform Concentrations, Wells Street (CSO Area) and Brown Deer Road (Separate Drainage Area), Milwaukee River, Milwaukee, WI | 11 |
| 7 | Wet Weather Fecal Coliform Concentrations, Wells Street (CSO Area), and Brown Deer Road (Separate Drainage Area), Milwaukee River, Milwaukee, WI | 11 |
| 8 | Single Purpose and Multiple Purpose Stormwater Pollution Control Costs for US | 13 |
| 9 | Example Solution Methodology | 16 |
| 10 | Construction Cost Example: Storage Facilities | 18 |
| 11 | Instrumentation for Total System Management | 21 |
| 12 | Simulation Models for Total System Management | 23 |
| 13 | Land Management | 30 |
| 14 | Porous Asphaltic - Concrete Features | 32 |
| 15 | Deicing Chemical Control (Land Management/Non-Structural) | 35 |
| 16 | Erosion - Sedimentation Control: Products | 38 |
| 17 | Collection System Control | 40 |

FIGURES (Concluded)

Number Page

18 Isometric View of Swirl Regulator/Concentrator . . . . . . . . . 43

19 Storage. . . . . . . . . . . . . . . . . . . . . . . . . . . . . 45

20 Results of Controlling Storm Flow by Storage . . . . . . . . . . 46

21 Treatment. . . . . . . . . . . . . . . . . . . . . . . . . . . . 48

22 Sludge/Solids. . . . . . . . . . . . . . . . . . . . . . . . . . 52

23 Integrated Systems . . . . . . . . . . . . . . . . . . . . . . . 54

# TABLES

Number Page

1 Summary: Storm and Combined Sewer Program . . . . . . . . . 3

2 Metals Discharged to the Harbor from New York City Sources . 7

3 Instrumentation: Products. . . . . . . . . . . . . . . . . . . 22

4 Levels of Urban Water Management Analysis. . . . . . . . . . 24

5 Pollutant Analysis . . . . . . . . . . . . . . . . . . . . . 25

6 Runoff Analysis. . . . . . . . . . . . . . . . . . . . . . . 26

7 Simulation Models: Products . . . . . . . . . . . . . . . . . 28

8 Cost Comparison Between Surface Ponding Techniques and Conventional Sewer Installations . . . . . . . . . . . . . . . 31

9 Advanced Street Cleaner Pollutant Recovery Percentages . . . 33

10 Swirl Regulator/Concentrator: Suspended Solids Removal. . . 44

11 Swirl Regulator/Concentrator: $BOD_5$ Removal. . . . . . . . . 44

12 Wet-Weather Treatment Plant Performance Data . . . . . . . . 50

13 Sludge/Solids: Products . . . . . . . . . . . . . . . . . . 53

14 Significant Documents Completed. . . . . . . . . . . . . . . 56

15 Significant Documents Anticipated. . . . . . . . . . . . . . 57

16 Typical Capital Costs for SCS Control/Treatment (ENR 2000) . 59

17 Des Moines: Control Costs vs. Violations of DO Standard (4 ppm). . . . . . . . . . . . . . . . . . . . . . . . . . . 61

## ACKNOWLEDGMENTS

The assistance and thoughtfulness of Francis J. Condon of the Waste Management Division, EPA, Washington, D.C., in the preparation of the "Erosion/Sedimentation Control: Products" and "Hydrologic Modification Category Status" subsections, is gratefully acknowledged.

Betty H. Mohary of the Storm and Combined Sewer Section deserves special recognition for her perseverance, unselfish devotion, and extreme effort in putting this report together.

The cooperation of Richard Traver, Russell Bowden, Mary Landante Kathy Rozgonyi and Linda Zipfel of the Storm and Combined Sewer Section, Edison, N.J.,is acknowledged with sincere appreciation.

# INTRODUCTION

Control and treatment of stormwater discharges and combined sewage overflows from urban areas are problems of increasing importance in the field of water quality management. Over the past decade much research effort has been expended and a large amount of data has been generated, primarily through the actions and support of the U.S. Environmental Protection Agency's Storm and Combined Sewer Research and Development Program.

The products of the Program (Figure 1.) as it will be presented will be divided into the following areas, common to the major elements of Combined Sewer Overflow Pollution Control, and Sewered and Unsewered Runoff Pollution Control: Problem Definition, User Assistance Tools (Instrumentation, Computers), Land Management, Collection System Control, Storage, Treatment, Sludge and Solids, Integrated Systems, and Technical Assistance and Technology Transfer.

Table 1. breaks down these categories into more specific elements which will be discussed individually. There have been many projects under the Program -- about 150, so only a basic Program direction and the more significant products, both completed and anticipated, will be highlighted. References are cited for completed Program reports (numerically indicated), ongoing Program projects (indicated by "P" numbers), and in-house and miscellaneous documents (indicated by "R" numbers).

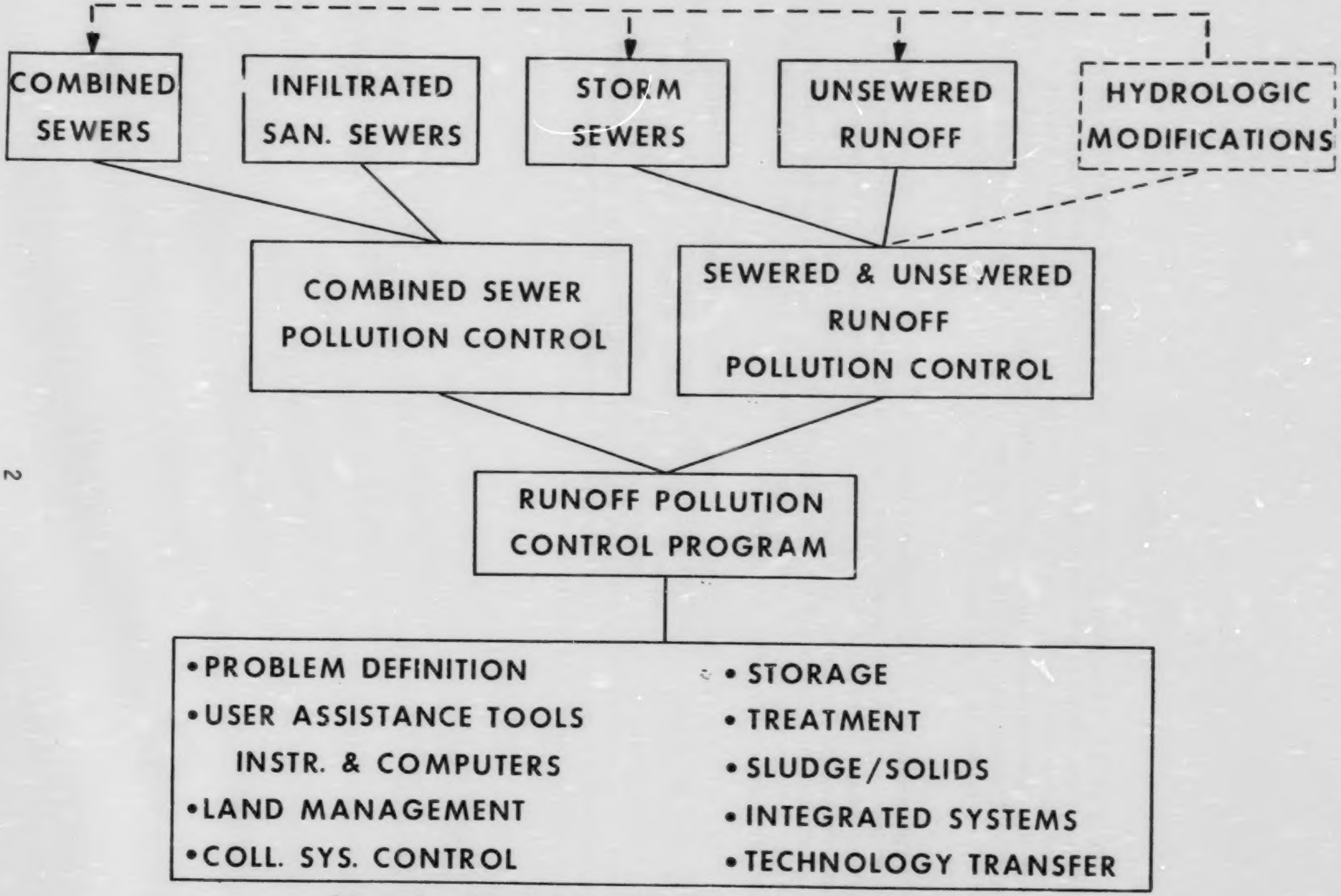

COMBINED SEWERS
INFILTRATED SAN. SEWERS
STORM SEWERS
UNSEWERED RUNOFF
HYDROLOGIC MODIFICATIONS
COMBINED SEWER POLLUTION CONTROL
SEWERED & UNSEWERED RUNOFF POLLUTION CONTROL
RUNOFF POLLUTION CONTROL PROGRAM
•PROBLEM DEFINITION
•USER ASSISTANCE TOOLS INSTR. & COMPUTERS
•LAND MANAGEMENT
•COLL. SYS. CONTROL
• STORAGE
• TREATMENT
• SLUDGE/SOLIDS
• INTEGRATED SYSTEMS
• TECHNOLOGY TRANSFER

Figure 1. EPA Storm and Combined Sewer R&D Program

| CATEGORIES | INITIATED/ACCOMPLISHED | ONGOING |
|---|---|---|
| PROBLEM DEFINITION | | -Direct rec. water/source loading factor analysis<br>-Dev. S&CS strategy document<br>-Analyze optimum S&CS/DWF T/C combinations |
| Characterization | Prelim. appraisals CSO/SW prob., CSO/SW char., deicing, sed./eros., loading factors, rec. water impacts, nat'l assess. impacts/costs | |
| Solution Methodology | SOTA S&CS tech., plan/select guide, conduct of SW studies, SOTA's sed./eros. & deicing control, unit cost factor dev. | |
| USER ASSISTANCE TOOLS | | -Verif. magnetic flowmeter for simultaneous press/gravity flow meas. (supplement)<br>-Demo in-situ TOC anal. & storm flow sampler (Syracuse-supplement)<br>-Dev. syst. analysis program for quantification/handling of CSO sludge/solids<br>-Dev. autom. oper. model for real-time control w/rain fall predict.<br>-Hydr. model for steep slopes (supplement) |
| Instrumentation | Raingage, flow measuring, sampling, monitoring, control | |
| Simulation Models | Simplified, detailed/complex, operational, dissemination | |
| LAND MANAGEMENT | NON-STRUCTURAL: | -Eval. effect of sed. trapping efficiency of off-stream det./ret.<br>-Demo in-situ hydrophobic substance<br>-Demo sed./eros. control techniques in SE USA (supplement)<br>-Demo improved street cleaning practices |
| Retention/detention | Land use planning, upstream impoundment (structural), porous pavement | |
| Enforced controls | Air pollution, eros./sed., cropping, berms, chemical use, hydrophobic, deicing | |
| Neighborhood sanitation | Street cleaning, solid waste management | |
| COLLECTION SYSTEM CONTROLS | | -Demo periodic sewer flushing: CSO 1st flush relief<br>-Eval. strength increases from sulfur impregnation of concrete pipe<br>-Dev. autom. operational model for real-time control w/rainfall predict. |
| Sewer separation | May require separate treatment system | |
| Runoff inlet/catch basin | Effectiveness eval., improved design, cleaning | |
| Sewers | "First flush" relief: flushing/cleaning, new designs (low flow carrying vel. and added storage), I/I prevent and control (with manuals), polymers to increase capacity | |
| Improved regulators and tide gates | Positive control, increased diversion to treatment, swirl & helical, fluidic reg. | |
| Remote monitoring with supervisory control | Provides storage/discharge options | |
| Fully automated control | Automates storage/discharge options | |
| STORAGE | | |
| In-Line | Use excess sewer capacity | |
| Off-Line | Surface (rect. tanks, earthen basins, abond. quarries), subterrain. (natural formations, silos & tunnels), underwater, colids impacts | |
| TREATMENT | | -Demo fine screening/microstraining, swirl reg. and high-rate disinf. by ClO$_2$/Cl$_2$ and mixing incl: resid. toxic/carcinogenic Cl$_2$ comp. viral disinf. eval.) (Syracuse-supplement)<br>-Feas. of land disposal (Envirex-supplement) |
| Physical treatment with and without chemicals | Fine screening, microstraining, sed., filt., dissolved air flotation, swirl/spiral separation | |
| Biological treatment | Contact stabilization, trickling filters, lagoons, rotating biological contactors. Generally assoc. w/continuously operated plant | |
| Physical-chemical | Precipitation, filtration, adsorption, ion exchange, break-pt Cl$_2$ | |
| Disinfection | Chlorination, hypochlorination, ozonation, chlorine dioxide, on-site gen., high-rate, mixing, micro-organism indicator study (pathogen, virus), 2-stage | |
| Land disposal | Marsh land | |
| SLUDGE/SOLIDS | | -Evaluate: methods of ultimate disposal of WWF solids and impacts of WWF sludges/solids on DWF plant (Envirex-supplement) |
| Characterization/Quantification | Classification requirement, treatability, vital parameters, amount, solids content | |
| Treatment handling schemes | On-site vs DWF trmt., land disposal | |
| Process evaluations | Thickening, digestion, centrifugation, vacuum filtration, incineration | |
| INTEGRATED SYSTEMS (Varies) | Most common master plan approach | |
| Storage/treatment | Pump-back, sed. in storage, disinfection, break-even econ. w/treatment | |
| Dual use WWF/DWF (storage/treatment | Lagoon storage/treat., HRTF, contact stab., P-C, hi-rate filter, equalization, combined sewers | |
| Control/treatment/reuse | Treatment-park, new town devel. (land mgmt-treat), storage/treat. marina feas., lakelets for storage/treat./reuse | |
| TECHNICAL ASSISTANCE AND TECHNOLOGY TRANSFER | | -Continuous (15% - 20% of prog. time)<br>NOTE: Anticipate increase in EPA construction grant (201) and planning grant (208) assist. due to CSO emphasis |
| Consultation to Fed., state, local govts. and quasi-govt. agencies | EPA, OAWP (needs surveys): EPA TT (seminars, film production); EPA Reg. receiving H$_2$O impact studies; EPA Hq and Regions on 201/208 studies and seminars; Reg. V on 108 grants; NSF, DOT, OWRT (reviews, confer, steering committees); CEQ & NCWQ (proposal and rept reviews, joint nat'l assess. projects) | |
| Public Inf. Requests | Documents, lectures, films, confer., articles, reports, example methodology for prob. solution, conf. moderator, prog. committees | |
| Consultation to foreign govt. and international confer. | TT (France, Japan, Denmark, Norway, Sweden, Canada, Netherlands, Australia, New Zealand); Canadian (TAG) IJC (steering com.) IAWPR (confer. & prog. committees); various conferences and publications | |
| In-House seminars | Various tech. areas; overviews | |
| SWMM | Short course.; user's assistance manuals/dissemination | |
| Higher Education | SCS prog. university course man. | |
| Planning/design/SOTA/assess manuals and extramural publications | Overall prog. concepts, sol. method, sampling/anal., costs, specific processes | |

Table 1. Summary Storm and Combined Sewer Program

## PROBLEM DEFINITION

The program starts with "Problem Definition" broken into "Characterization" and "Solution Methodology" (Figure 2.).

The background of sewer construction led to the present urban runoff problem. Early drainage plans made no provisions for storm flow pollutional impacts. Untreated overflows occur from storm events giving rise to the storm flow pollution problem.

Simply stated the problem is:

*"When a city takes a bath, what do you do with the dirty water?"*

Three types of discharges are involved: combined sewer overflows (CSO), storm drainage in separate systems, and overflows from infiltrated sanitary sewers. Significantly, the storm path and collection system configuration may have a pronounced influence on combined overflow quality, resulting in simultaneous discharge mixtures of sewage and runoff at different points, varying from raw to highly diluted as the system adjusts to a particular storm pattern. The problem constituents of general concern are visible matter, infectious bacteria, organics, and solids and in addition may include nutrients, heavy metals and pesticides.

## CHARACTERIZATION

### Representative Concentrations

Figure 3. gives some representative concentrations for comparison purposes. As shown the average BOD concentration in combined sewer overflow is approximately one-half the raw sanitary sewage BOD. However, storm discharges must be considered in terms of their shockloading effect due to their great magnitude. A not uncommon rainfall intensity of 1 in./hr will produce urban flowrates 50 to 100 times greater than the dry-weather flow (DWF) from the same area. Even separate storm wastewaters are significant sources of pollution, "typically" characterized as having solids concentrations equal to or greater than those of untreated sanitary wastewater, and BOD concentrations approximately equal to those of secondary effluent. Bacterial contamination of separate storm wastewaters is typically 2 to 4 orders of magnitude less than that of untreated sanitary wastewaters. Significantly, however, it is 2 to 4 orders of magnitude greater than concentrations considered safe for water contact activities.

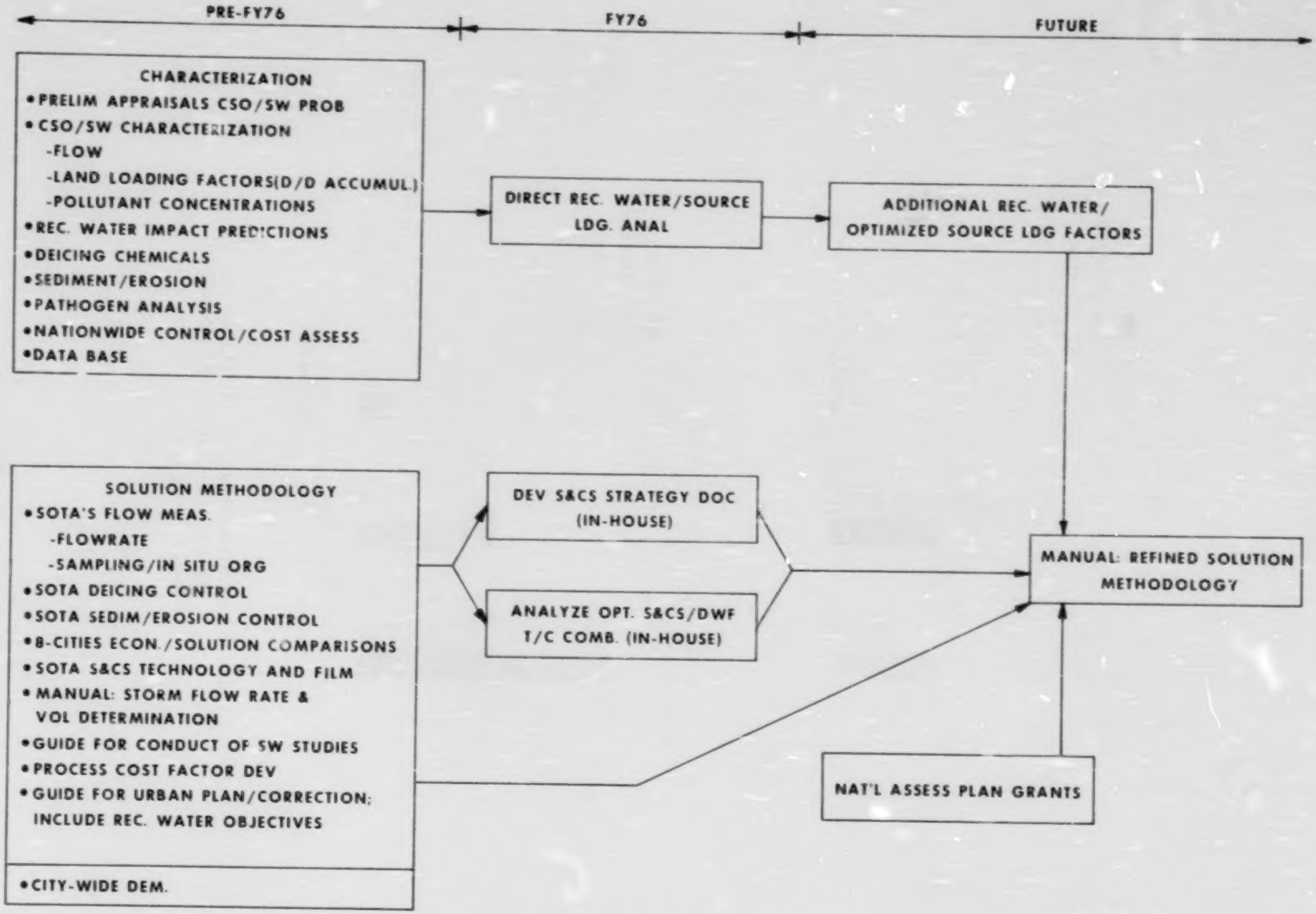

PRE-FY76
FY76
FUTURE
CHARACTERIZATION
•PRELIM APPRAISALS CSO/SW PROB
•CSO/SW CHARACTERIZATION
-FLOW
-LAND LOADING FACTORS(D/D ACCUMUL.)
-POLLUTANT CONCENTRATIONS
•REC. WATER IMPACT PREDICTIONS
•DEICING CHEMICALS
•SEDIMENT/EROSION
•PATHOGEN ANALYSIS
•NATIONWIDE CONTROL/COST ASSESS
•DATA BASE
DIRECT REC. WATER/SOURCE LDG. ANAL
ADDITIONAL REC. WATER/ OPTIMIZED SOURCE LDG FACTORS
SOLUTION METHODOLOGY
•SOTA'S FLOW MEAS.
-FLOWRATE
-SAMPLING/IN SITU ORG
•SOTA DEICING CONTROL
•SOTA SEDIM/EROSION CONTROL
•8-CITIES ECON./SOLUTION COMPARISONS
•SOTA S&CS TECHNOLOGY AND FILM
•MANUAL: STORM FLOW RATE & VOL DETERMINATION
•GUIDE FOR CONDUCT OF SW STUDIES
•PROCESS COST FACTOR DEV
•GUIDE FOR URBAN PLAN/CORRECTION; INCLUDE REC. WATER OBJECTIVES
•CITY-WIDE DEM.
DEV S&CS STRATEGY DOC (IN-HOUSE)
ANALYZE OPT. S&CS/DWF T/C COMB. (IN-HOUSE)
MANUAL: REFINED SOLUTION METHODOLOGY
NAT'L ASSESS PLAN GRANTS

Figure 2. Problem Definition

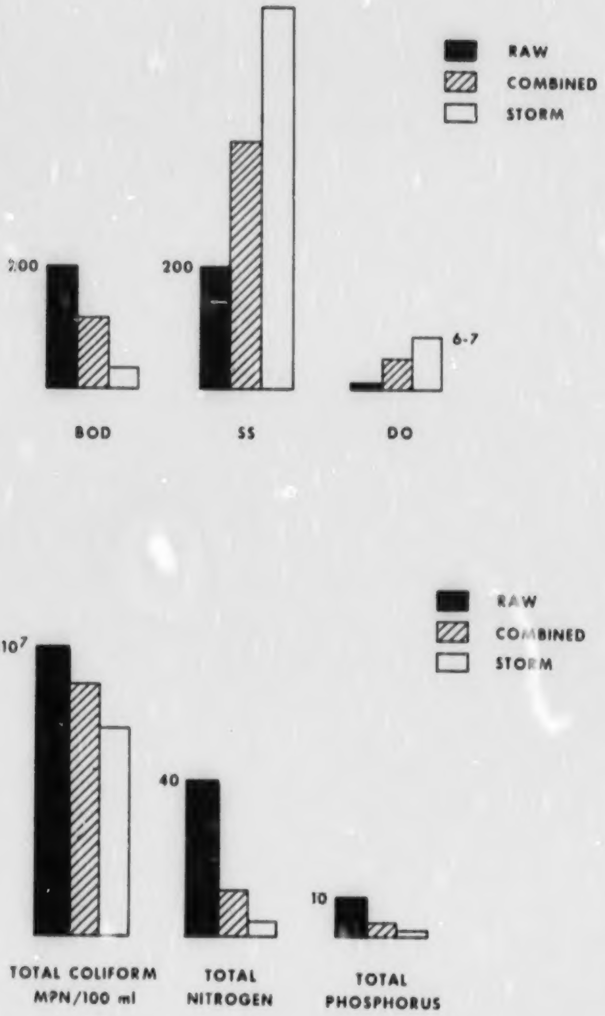


Figure 3. Representative Strengths of Wastewaters (Flow Weighted Means in mg/l)

Microbiological studies of both sanitary sewage and storm runoff have shown a consistently high recovery of both pathogenic and indicator organisms (160). The most concentrated pathogens were Pseudomonas aeruginosa and Staphylococcus aureus at levels ranging from $10^3$ to $10^5$ and from $10^0$ to $10^3$/100ml, respectively. Salmonella and enteroviruses, though frequently isolated were found at levels of only $10^0$ to $10^4$/10 liters of urban runoff. This strongly indicates that all types of urban runoff, in general, are hazardous to health.

## Representative Loads

From 40% to 80% of the total annual organic loading entering receiving waters from a city is caused by sources other than the treatment plant (R-1). Assuming treatment plants are operating properly, during a single storm event, from 94% to 99% of the organic load and almost all settleable solids are attributed to wet-weather flow (WWF) sources (R-1).

The runoff of toxic pollutants, particularly heavy metals, is also high--considerably higher than typical industrial discharges. For example, New York Harbor receives metals from treatment plant effluents; discharges from combined sewer overflows and separate storm sewers; and untreated wastewater included in the CSO and from sewered areas not yet served by treatment plants. As can be seen in Table 2., urban runoff is the major contributor of heavy metals to the Harbor (R-2).

## Potential Impacts

Approximately one-half of the stream miles in this country are water quality limited and 30% of these stream lengths are polluted to a certain degree with urban runoff. Hence, generally speaking, secondary treatment of DWF is not sufficient to produce required receiving water quality; and control of runoff pollution becomes an alternative for maintaining stream standards. Accordingly, both water quality planning and water pollution abatement programs need to be based on an analysis of the total urban pollution loads.

**TABLE 2. —Metals Discharged to the Harbor from New York City Sources**

| Source | Cu | Cr | Ni | Zn | Cd |
|---|---|---|---|---|---|
| Plant effluents | 1,410 | 780 | 930 | 2,520 | 95 |
| Runoff * | 1,990 | 690 | 650 | 6,920 | 110 |
| Untreated wastewater | 980 | 570 | 430 | 1,500 | 60 |
| Total weight (lb/day) | 4,380 | 2,040 | 2,010 | 10,940 | 265 |
| Weighted average concentration (mg/l) | 0.25 | 0.12 | 0.11 | 0.62 | 0.015 |

*In reality, shockload discharges are much greater.

Until the urban stormwater situation is analyzed and efficient corrective measures taken, there is little or no sense in seeking higher levels of treatment efficiency in existing plants. For example,

- In Roanoke, VA domestic waste load removal was upgraded from 86% to 93%, yet there was no dramatic reduction in the BOD load (3.2 million pounds before upgrading, compared to 3.1 million pounds after)(41).
- If Durham, NC provided 100% removal of organics and suspended solids from the raw municipal waste on an annual basis, the total reduction of pollutants discharged to the receiving water would only be 59% of the ultimate BOD, and 5% of the suspended solids (112).

These examples are for separate systems. Communities with combined systems offer a potentially greater pollutional impact since additional loads come from domestic wastewaters, dry-weather sediment wash-out, and more impervious and populated lands.

## Receiving Water Quality Impacts

For the aforementioned Durham study it was found that during storm flows, dissolved oxygen content of the receiving watercourse was independent of the degree of treatment of municipal wastes beyond secondary treatment. Oxygen sag estimates were unchanged even if the secondary plant was assumed upgraded to zero discharge, and stormwater discharges governed the oxygen sag 20 percent of the time.

There is an R&D study (P-68) in the Milwaukee area to determine water quality impacts from wet-weather discharges. This study is being worked in conjunction with a 201, Step 1 construction grant for the evaluation of combined sewer overflow pollution and control; and will provide the necessary "receiving water impact" basis for these evaluations.

Early results from direct receiving water sampling in the Milwaukee River provide strong evidence of CSO impacts on intensifying D.O. sag and increasing fecal coliform concentration. Figure 4. represents D.O. analyses for the Wells Street sampling station that lies at the downstream portion of the combined sewer area. Samples were collected at three hour intervals during 72 hours of dry weather during June 1975, averaged for the stream cross-section, and followed approximately nine days of antecedent dry weather. D.O. values hovered around 6 to 8 mg/l.

Figure 5. is for the same Wells Street location representing data from six days of monitoring following a 0.26 inch rainfall on October 14-15, 1975. Continuous monitoring at the site showed D.O. levels between 5.0 and 7.8 mg/l for the three days prior to rainfall. (The lag between the end of the storm and beginning of data acquisition was due to equipment malfunction.) The graph indicates a highly significant D.O. sag to zero mg/l and six days after the storm required for recovery.

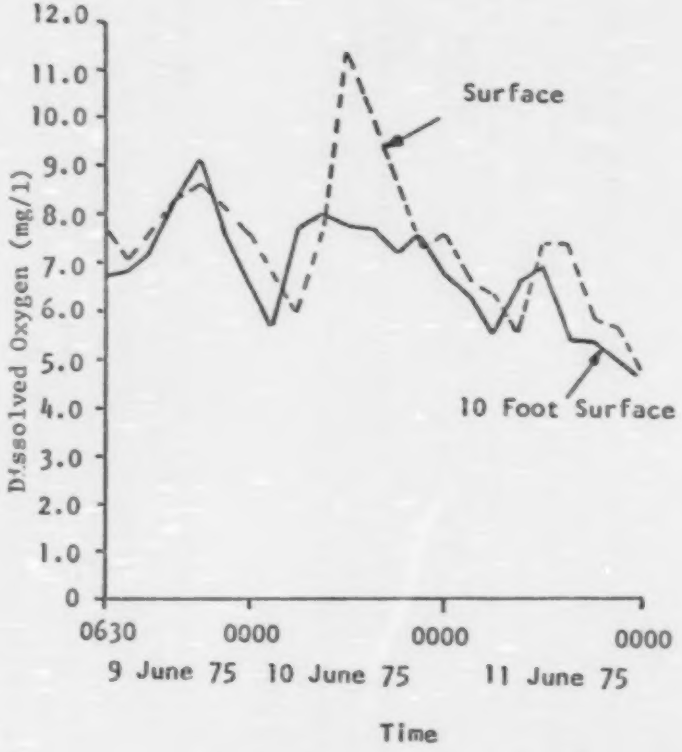


Figure 4. Dry Weather

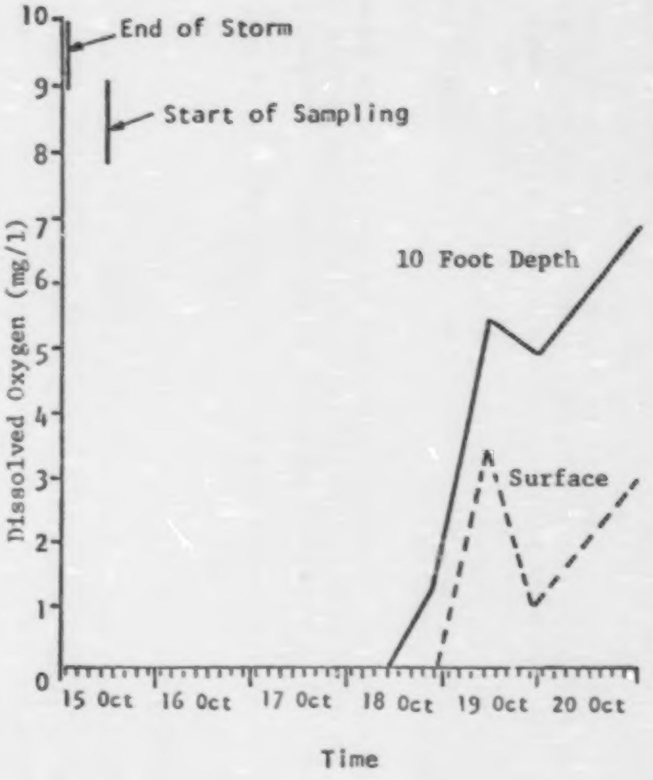


Figure 5. Wet Weather

Dissolved Oxygen Concentration, Wells Street
Milwaukee River, Milwaukee, WI

Adverse combined sewer overflow effects on fecal coliform concentrations in the Milwaukee River in the proximity of Lake Michigan were also deciphered. Figures 6. and 7. depict fecal coliform in the Milwaukee River during the same dry- and wet-weather monitoring periods as in Figures 4. and 5., respectively. Additionally, Figures 6. and 7. contain the Brown Deer Road monitoring site which is well above the intensely urbanized combined sewer overflow area. There is nearly a two log increase in enteric microorganisms downstream in the CSO area after wet-weather discharges indicating a potential health hazard for the nearby Lake beach fronts. Brown Deer Road showed no significant difference in fecal coliform concentration.

Due to Health Department findings, shell fishing must cease in Narragansett Bay in the vicinity of the Providence, RI overflows for periods of seven and ten days following rainfalls of one-half and one inch, respectively.

Other studies (P-15, 157,R-3) based on mass balance effects of urban runoff in receiving waters have reinforced these findings.

## Erosion/Sediment Impacts

Erosion-sedimentation causes the stripping of land, filling of surface waters, and water pollution. Urbanization causes accelerated erosion, raising sediment yields two to three orders of magnitude from $10^2$ - $10^3$ tons/sq mi/yr to $10^4$ - $10^5$ tons/sq mi/yr (164). At the present national rate of urbanization, i.e., 4,000 ac/day, erosion/sedimentation must be recognized as a major environmental problem.

## Characterization: Products

Past characterization studies for storm flow provide a data base for pollutant source accumulation, and hydraulic and pollutant loads (2,20,34,35, 41,47,51,53,54,59,60,63,65,67,73,81,82,83,88,102,123,124,127,128,143,149). A computerized data base and retrieval system has been developed for urban runoff (P-49). The data base contains screened and reasonably accurate data that is intended for model verification and future study area data synthesis -- especially useful to 201 and 208 planning agencies.

Besides the more generalized characterization studies, specific studies have been carried out for deicing salt (67,109,86), sediment/erosion (129), and pathogenic impacts (160) from storm flows.

## Nationwide Cost Assessment

### Sewer Separation --

The concept of constructing new sanitary sewers to replace existing combined sewers has largely been abandoned for pollution control due to enormous costs, limited abatement effectiveness, inconvenience to the public, and extended time for implementation. The use of alternate measures for combined sewer overflow control could reduce costs to about one-third the cost for separation (2,102). It is emphasized that sewer separation would not cope with the runoff pollution load.

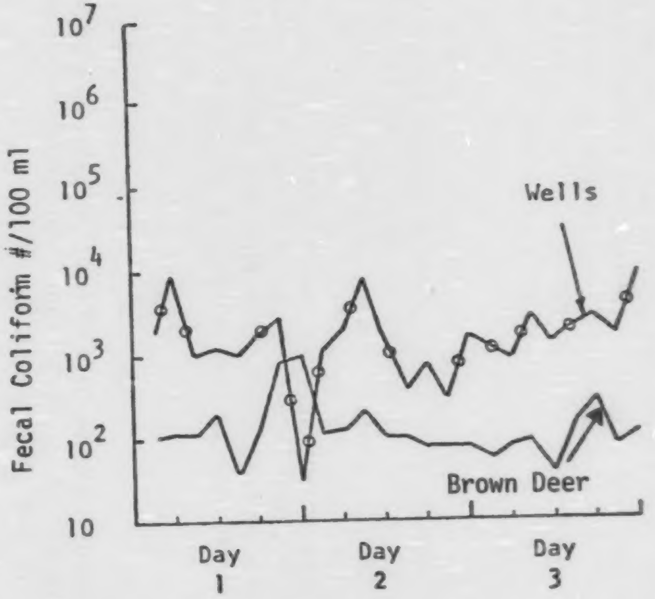


Figure 6. Dry Weather

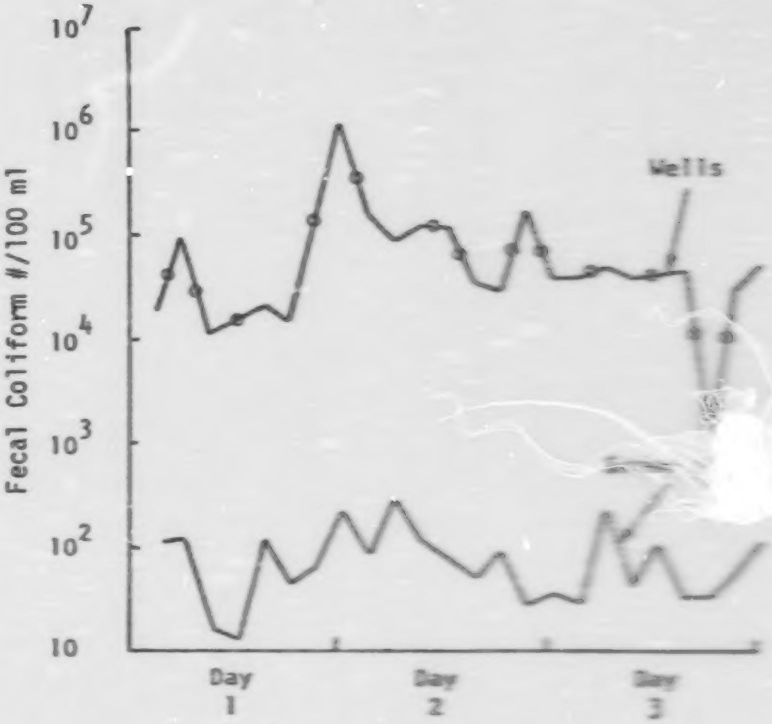


Figure 7. Wet Weather

Fecal Coliform Concentrations, Wells Street (CSO Area)
& Brown Deer Road (Separate Drainage Area)
Milwaukee River, Milwaukee, WI

### High Costs Implied --

However, even in alternate approaches high costs have been implied. The 1974 Needs Survey (R-4), the 1967 EPA survey by the American Public Works Association (2), and the 1975 National Commission on Water Quality (NCWQ) Report (R-5), identified national costs for abating combined sewer overflow pollution at $26 billion, or approximately one-fourth of the total for municipal sewage control. The cost of abating separate stormwater pollution was estimated at $235 billion by the Needs Survey and $173 billion (for 75% BOD reduction) by another NCWQ report (R-6).

There must be a more accurate assessment of the problem both nationwide and regional to provide the necessary foundation for policy and law making, and firmer pollution abatement targets -- realistically, can a job be done for the money allotted?

### New R&D Estimates Imply Lower Costs--

The recently completed Nationwide Assessment report (157) has attempted to more accurately assess these national cost estimates by reflecting a more logical consideration of such items as: climate, land usage, and degree of urbanization; pollution abatement of storm flow only and not separate, conventional flood control; appropriate design flows; and the benefits of optimized coordinated systems of smaller storage-treatment units not taken into consideration in earlier estimates. The resultant national cost for combined sewer overflow and separate stormwater pollution control was $23 billion at 75% BOD removal (Curve A, Figure 8.) (157). It is estimated that the incremental costs for combined sewer overflow pollution abatement alone would be $9 billion (Curve D, Figure 8).

Additional national cost reductions were shown by the multi-purpose coordinated use of wet and dry weather flow treatment facilities, and storm flow storage facilities used as dual sedimentation-treatment processes (see Curve B, Figure 8.). Within certain control levels best management practices, e.g., street cleaning and sewer flushing, could further reduce control costs (Curve C, Figure 8.).

When compared to prior studies the major reduction in the national figure for stormwater control is attributable to discounting storm sewer line construction (at $84 billion) and flood control (at $73 billion). These new estimates are admittedly limited because of required assumptions and the simplistic approach taken; but the point is, R&D should not shy away from separate stormwater research and control implementation based on even rougher preliminary surveys (e.g., the 1974 Needs or NCWQ surveys), if what is required is better estimating procedures; especially when stormwater pollution is site specific, and its abatement may be cost-effective in certain areas of the country.

## SOLUTION METHODOLOGY

The second area under Problem Definition, "Solution Methodology" naturally followed initial "Characterization" for providing a uniform and necessary background for the user community.

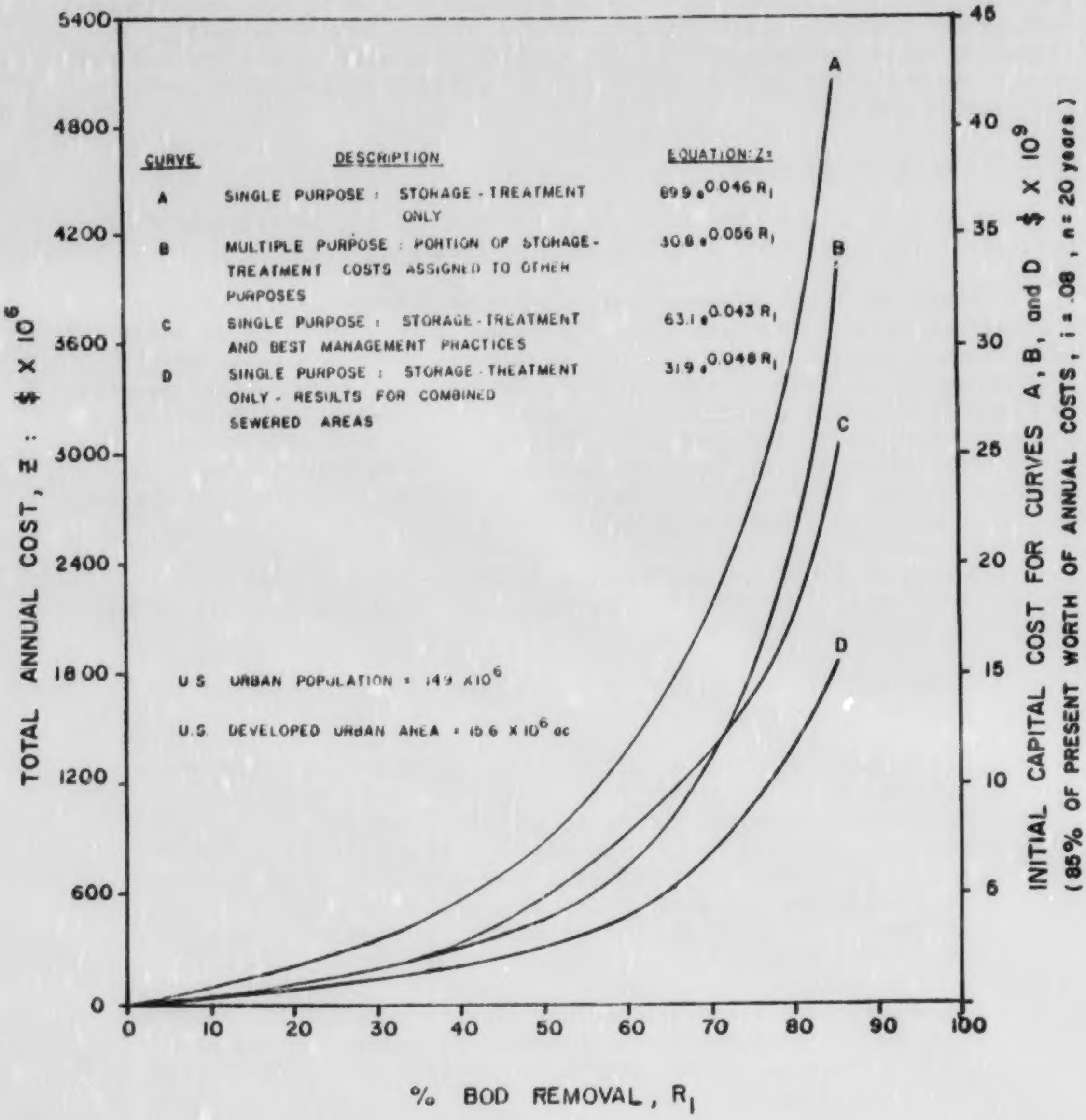


Figure 8. Single Purpose and Multiple Purpose Stormwater Pollution Control Costs for US

## More Accurate Problem Assessment

Considering the limitations in the presently available data base, the first and most fundamental approach should be a more accurate assessment of the problem. Ideally, this should involve acquiring data on a city-wide basis for both DWF and wet-weather flow (WWF) including upstream-downstream pollutant mass balances and the effects of the waste loads on the receiving waters.

## Cost-Effective Approach

Integrated with a more accurate assessment is the consideration of cost-effective approaches to WWF pollution control.

Present abatement alternatives exhibit an extraordinary range of cost-effectiveness. For example, cost-effectiveness in terms of dollars/lb of pollutant removed for an alternative such as storage plus primary treatment, varies over a range of 75:1, depending on such factors as location and land costs, type and condition of sewerage systems, pollution loads, and type of storage configuration. This very high cost-effectiveness variability demonstrates the irrationality of any attempt to prescribe uniform national standards for the technology of total urban load abatement as opposed to requiring site-specific studies.

There is an excellent opportunity to bring down the high costs implied for storm flow control. The most cost-effective solution methodology must thoroughly consider:

1. Wet-weather pollution impacts in lieu of blindly upgrading existing municipal plants.

2. Structural vs. land management and non-structural techniques. Studies have indicated that it may be cheaper to remove pollutants from the source by such measures as street, catch basin, and sewer cleaning than by eliminating them by downstream treatment. Certain land use, zoning, and construction site erosion control practices are other ways of alleviating the solids burden to the receiving stream or treatment plant;

3. Integrating dry and wet-weather flow systems to make maximum use of the existing sewerage system during wet conditions and maximum use of wet-weather control/treatment facilities during dry weather; and

4. The segment or bend on the percent pollutant control vs. cost curve (see Figure 8. for example) where cost differences accelerate at much higher rates than pollutant control increases. This phenomena is caused by the need to size storage-treatment facilities at disproportionately greater capacities for the less frequent storm events required for higher percent pollutant controls.

Until two important philosophies are allowed to prevail, the high cost implications for wet-weather pollution abatement will continue. First, flood and erosion control technology must be integrated with pollution control technology so that the retention and drainage facilities required for flood and erosion control can be simultaneously designed for integrated dual-benefits of pollution control. Second, if land management and non-structural techniques are maximized and integrated, there will be less to pay for the extraction of pollutants from storm flows in the potentially more costly downstream plants.

## Example Solution Methodology

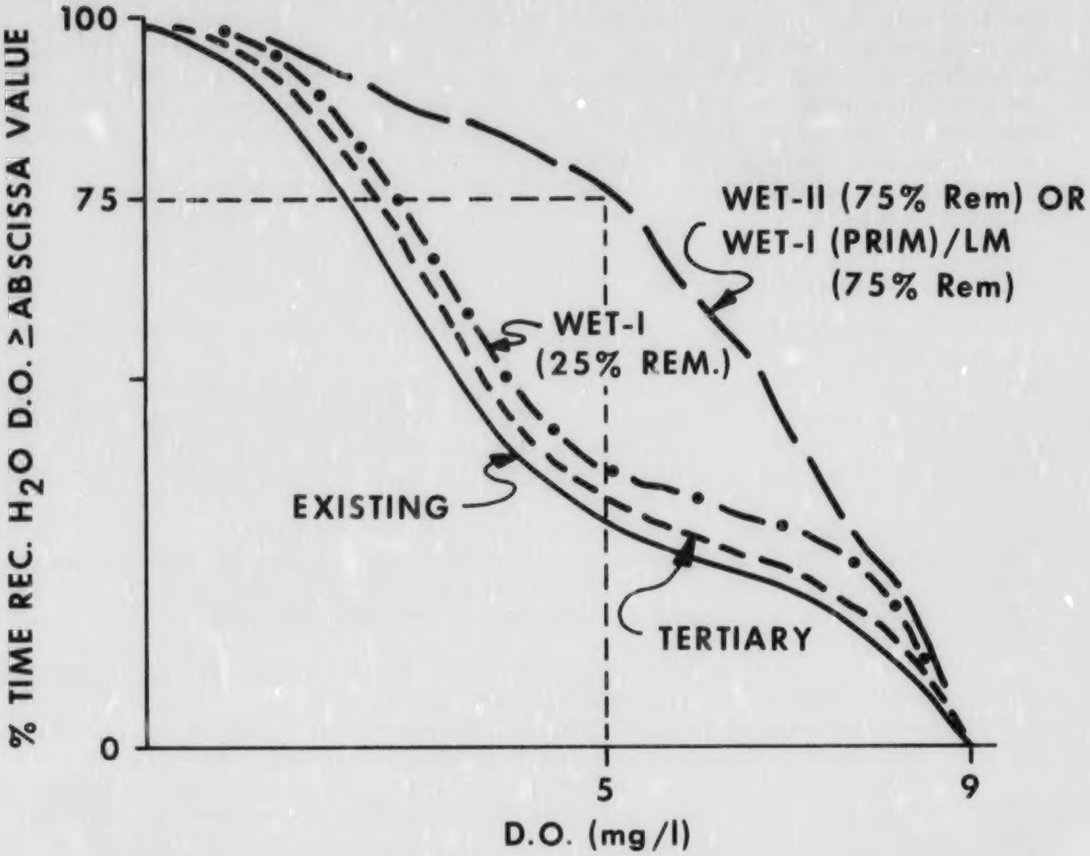
It is worthwhile to discuss a hypothetical example of a cost-effective solution methodology. Figure 9. represents one such approach. This case is for D.O.; actual studies should include other parameters and should represent at least one year of continuous data (at a minimum rainfall data). By this analysis a truer cost-effectiveness comparison can be made based on total time of receiving water impacts and associated abatement costs. For example, if a 5 mg/l D.O. is desired in the receiving water 75% of the time as a standard, an advanced form of wet-weather treatment or primary wet-weather treatment integrated with land management is required. The latter is the most cost-effective at $3M. This or similar methodologies (157, Chapter VII) can help set cost-effective standards as well as select alternatives.

At this juncture it is most appropriate to bring out the fact that there is a critical lacking of meaningful water quality standards--especially for storm flow transient effects! This limitation forces the use of (1) existing criteria not well backed up by ecological receiving water effects, or (2) arbitrary percent control of combined sewer overflow or storm discharges. A critical need exists for the technology development sectors to join together with the receiving water ecology sectors to define and establish wet-weather receiving water effects--for only then will the right benchmarks be available for proper solution methodology. It is felt that the present state-of-the-art is advanced far enough to generate land runoff pollutant loadings from different control options and subsequent receiving water pollutant concentration. By filling the important gap of an adequate set of receiving water quality standards to work with, the necessary foundation tools will be available for a true cost-effective solution methodology.

## Overcome Administrative Problems

It is essential to include these concepts to handle the job properly. However, there are basic problems in administration that must be overcome.

The autonomous Federal and local agencies and professions involved in flood and erosion control, pollution control, and land management and environmental planning must be integrated at both the planning and operation levels. Multi-agency grant coverage must be adequate to stimulate such an approach. For example, EPA would have to join with the Corps, Soil Conservation Service, Department of Transportation, and perhaps other Federal agencies as well as



| CONTROL ALTERNATIVES | % BOD REMOVAL | | COST ($\$\times10^6$) |
|---|---|---|---|
| | DRY WEATHER | WET WEATHER | |
| EXISTING | 85 | 0 | — |
| TERTIARY | 95 | 0 | 6 |
| WET-I (PRIMARY) | 85 | 25 | 1 |
| WET-II (ADV) | 85 | 75 | 6 |
| WET-I/LAND MGMT. | 85 | 75 | 3 |

Figure 9. Example Solution Methodology

departments of pollution control, sanitation, planning and flood control at the local level. EPA's present policy of funding construction will also need expansion to cover cost-effective land management and non-structural techniques promulgated by its planning grant approach.

## Solution Methodology: Products

Highlighted solution methodology products are the often referenced eight city studies (41,51,53,54,49,60,65,83) which involved an economic comparison of pollution control alternatives for both dry and wet weather flow.

The state-of-the-art text on urban stormwater management and technology (102) is considered an excellent program milestone and guide for planners and engineers. It organizes and presents more than 100 completed Program projects as of December 1973. The text is presently being updated and will include comprehensive guidelines for total city-wide, wet-weather pollution control planning and countermeasure selection (P-5). Other in-house Program documents (111, R-6a, R-6b, R-6c, R-6d, R-6e, R-6f, R-6g, R-6h, R-6i) must also be included in this category.

A film is available covering the entire Program, and in particular full-scale control technologies (R-7). Program seminar proceedings (6,40,96) with themes of "design, operation, and costs" have been published. Urban runoff seminar proceedings for 208 planning agencies (140a) are also available. Separate engineering manuals are available for urban storm flowrate and volume determination (140,123), storm sewer design (71), and conducting urban stormwater pollution and control studies (145). SOTA's on storm flow measuring (130) and sampling (87,133) have also been published. All these documents are valuable references for the planning and implementing of urban stormwater studies for PL 92-500, 201, Step 1, and 208 grants.

In the area of "unit cost information" a manual (156) is at press which contains summary unit cost graphs on construction and operation of the basic urban stormwater storage and treatment devices. An example on storage facility construction costs is presented in Figure 10. Additional cost information and equations can be obtained from the abovementioned text on urban stormwater management and technology (102), the SWMM user's manual (116), the nationwide stormwater assessment document (157), and the manual for preliminary (level I) stormwater control screening (153).

Other important and widely referenced SOTA manuals are available for deicing pollution (100,104) and erosion control (68,70,90,92,168,169). The SOTA document on size and settling velocity characteristics of particles in storm and sanitary water (115) is important because it offers information for physical treatability of suspended solids and anticipated settlement in receiving waters. More information of this nature, along with the availability of pollutants with the suspended solids, is needed. These, along with the aforementioned solution methodology documents, are or should be serving for 201 and 208 studies.

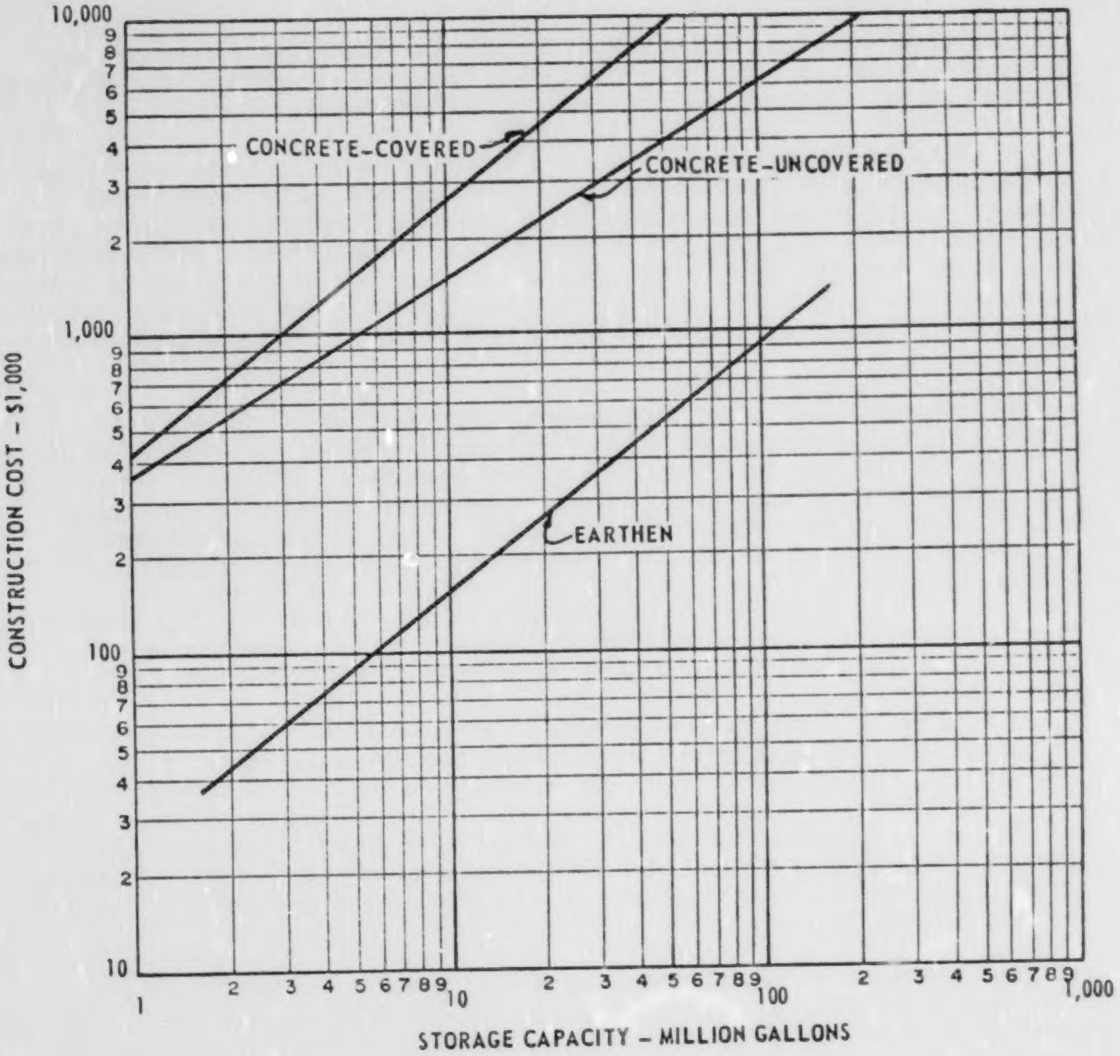


Figure 10. Construction Cost Example: Storage Facilities

Looking to the near future a city-wide demonstration (P-15) of a multifaceted approach methodology is nearing completion in Rochester, N.Y. The product from this study will serve as an example for other cities.

There is also an endeavor to study direct receiving water impacts along with verification of a water quality model. This task will serve as an important demonstration by lending credence to the implications of storm flow impacts. The previously discussed Milwaukee project (P-68) covers this objective. Other demonstration sites are being sought by the Program. Receiving water impacts have been included in an ongoing project in Lancaster, PA (P-4) and additional non-EPA funds to conduct a receiving water impact analysis for the ongoing Rochester project (P-15) have been secured.

In FY 78 the Program would like to initiate an assessment of the various 201 and 208 planning grants, and later a refined manual on solution methodology culminating Program objectives in the area of problem definition.

## USER ASSISTANCE TOOLS

The User Assistance Tools are divided into "Instrumentation" and "Simulation Models."

### INSTRUMENTATION

The qualitative and quantitative measurement of storm overflows is essential for planning, process design, control, evaluation, and enforcement. "Urban intelligence systems" require real-time data from rapid remote sensors in order to achieve remote control of a sewerage network. Sampling devices do not provide representative aliquots, and in-line measurement of suspended solids and organics is needed. Conventional rate-of-flow meters have been developed mainly for relatively steady-state irrigational streams and sanitary flows and not for the highly varying surges encountered in storm and combined sewers. A schematic of instrumentation development by the Program is shown on Figure 11.

The electromagnetic (P-45), ultra-sound (150), and passive sound (139) flowmeters have been developed to overcome these adverse storm flow conditions (which require dual pressure-gravity measurement of unsteady flows by non-intrusive instrumentation). Further demonstration of the electromagnetic and passive sound flowmeters will take place shortly. Passive sound instruments offer the additional benefit of extremely low power requirements rendering them amenable to installation at remote overflow locations (where power may not exist) and integration into city-wide, in-sewer, sensing, and control systems. A prototype sampler for capturing representative solids in storm flow, and overcoming storm flow adversities, has been developed and compared with conventional samplers. Favorable results have been obtained and a design manual (135) is available. Demonstration of two previously developed instantaneous, in situ monitoring devices for suspended solids (113) (based on the optical principle of suspended solids depolarizing polarized light) and TOC (126) were successfully conducted.

Separate SOTA reports for flow measurement (130) and sampling (87,133) have been mentioned under problem definition. A SOTA on organic analyzers (110) is also available. Because storm flow conditions are extremely adverse, the manuals and instruments developed for the Program in this area are useful for the monitoring of all types of waste flows.

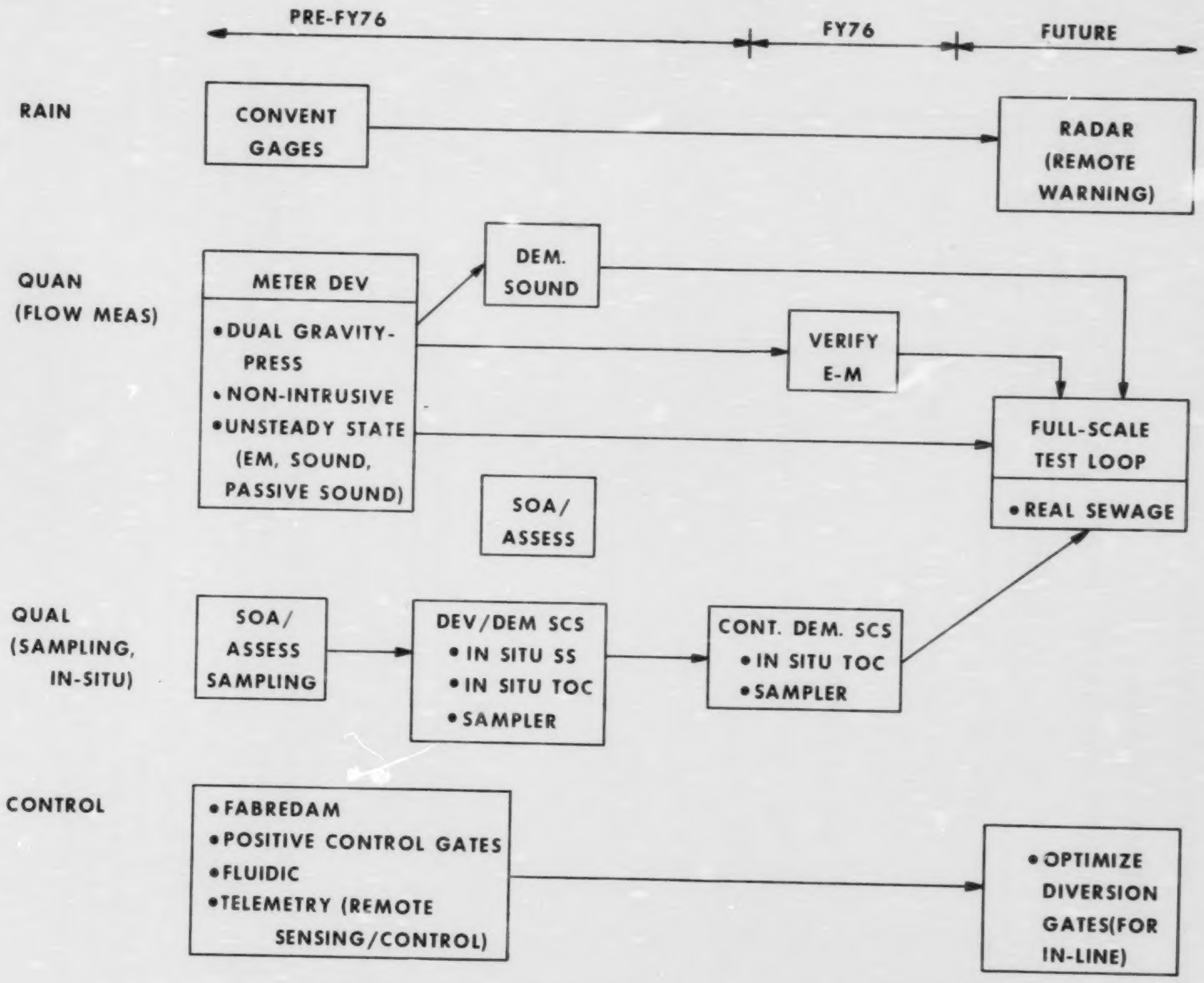

PRE-FY76
FY76
FUTURE
RAIN
CONVENT GAGES
RADAR (REMOTE WARNING)
QUAN (FLOW MEAS)
METER DEV
• DUAL GRAVITY-PRESS
• NON-INTRUSIVE
• UNSTEADY STATE (EM, SOUND, PASSIVE SOUND)
DEM. SOUND
VERIFY E-M
FULL-SCALE TEST LOOP
• REAL SEWAGE
SOA/ ASSESS
QUAL (SAMPLING, IN-SITU)
SOA/ ASSESS SAMPLING
DEV/DEM SCS
• IN SITU SS
• IN SITU TOC
• SAMPLER
CONT. DEM. SCS
• IN SITU TOC
• SAMPLER
CONTROL
• FABREDAM
• POSITIVE CONTROL GATES
• FLUIDIC
• TELEMETRY (REMOTE SENSING/CONTROL)
• OPTIMIZE DIVERSION GATES(FOR IN-LINE)

Figure 11. Instrumentation for Total System Management

Remote raingaging by radar is being considered for an automated combined sewer flow routing project in San Francisco (P-25).

## Instrumentation: Products

An instrumentation product summary is listed on Table 3.

Table 3. Instrumentation: Products

Flow Measuring Devices Development

- Electromagnetic (open-channel and press flow) (P-45)
- Ultra-sound (150)
- Passive Sound (139)

Sampler Development (135)

*In situ* suspended solids monitor development (113)

*In situ* TOC monitoring system development (126)

SOTA/Assessment reports

- Sampling (133)
- Flow measuring (130)
- Organics monitoring (110)

## SIMULATION MODELS

Math models are needed to predict complex dynamic responses to variable and stochastic climatological phenomena. Models have been subcategorized into three groups: (1) *simplified* for preliminary planning, (2) *detailed* for planning and design, and (3) *operational* for supervisory control (Figure 12.).

The Storm Water Management Model (SWMM) provides a detailed simulation of the quantity and quality of stormwater during a specified precipitation event. Its benefits for detailed planning and design have been demonstrated and the model is widely used. However, for many users it is too detailed; e.g., the 208 planning effort needs simplified procedures to permit preliminary screening of alternatives. Consequently, current Program thinking on urban water management analysis in general, and SWMM in particular, involves four levels of evaluation techniques ranging from simple to complex procedures that can be worked together. The major portions of all four levels have been developed (Table 4.).

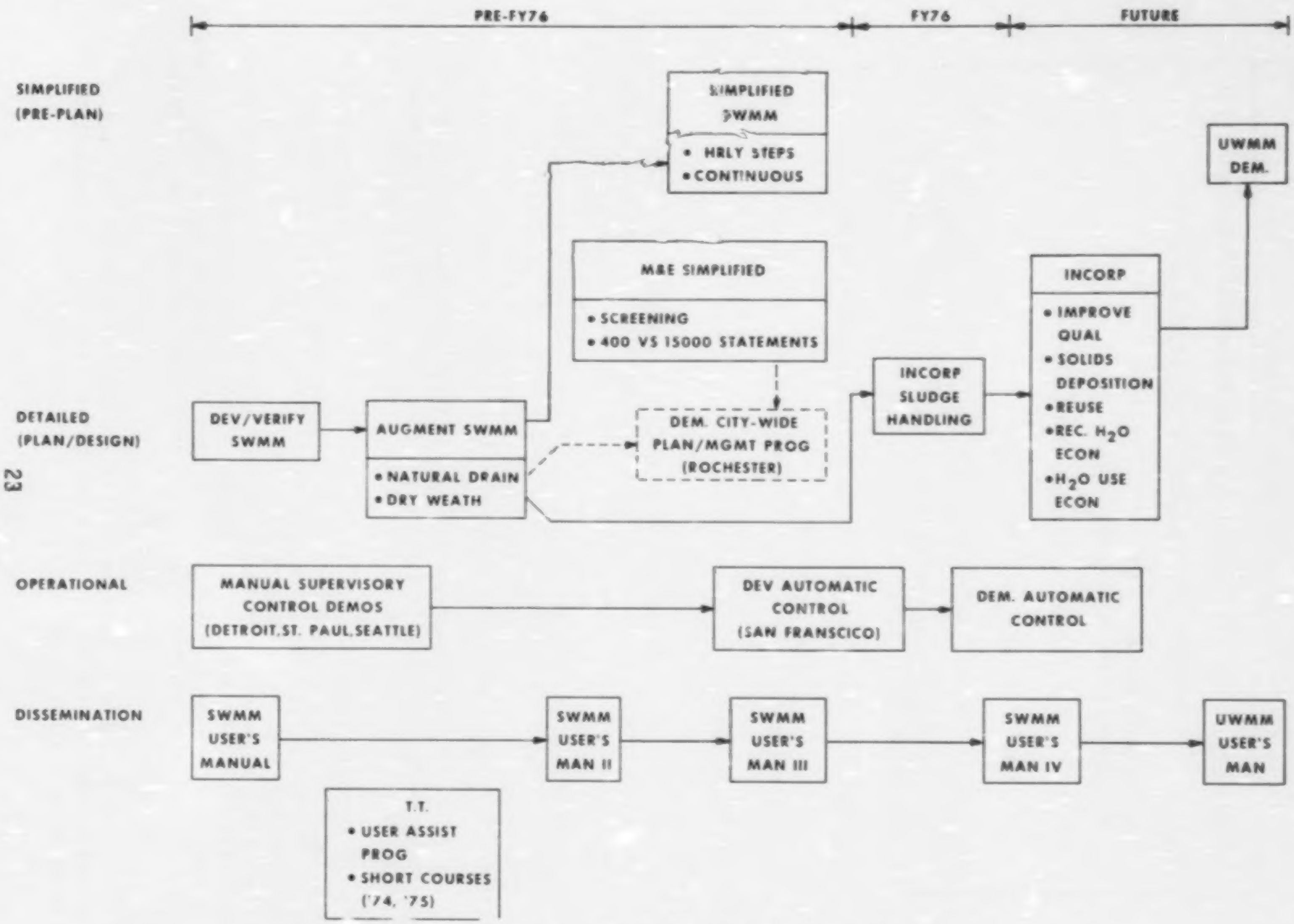

PRE-FY76
FY76
FUTURE
SIMPLIFIED (PRE-PLAN)
DETAILED (PLAN/DESIGN)
OPERATIONAL
DISSEMINATION
SIMPLIFIED SWMM
• HRLY STEPS
• CONTINUOUS
UWMM DEM.
M&E SIMPLIFIED
• SCREENING
• 400 VS 15000 STATEMENTS
INCORP
• IMPROVE QUAL
• SOLIDS DEPOSITION
• REUSE
• REC. H2O ECON
• H2O USE ECON
DEV/VERIFY SWMM
AUGMENT SWMM
• NATURAL DRAIN
• DRY WEATH
DEM. CITY-WIDE PLAN/MGMT PROG (ROCHESTER)
INCORP SLUDGE HANDLING
MANUAL SUPERVISORY CONTROL DEMOS (DETROIT, ST. PAUL, SEATTLE)
DEV AUTOMATIC CONTROL (SAN FRANSCICO)
DEM. AUTOMATIC CONTROL
SWMM USER'S MANUAL
SWMM USER'S MAN II
SWMM USER'S MAN III
SWMM USER'S MAN IV
UWMM USER'S MAN
T.T.
• USER ASSIST PROG
• SHORT COURSES ('74, '75)

Figure 12. Simulation Models for Total System Management

Table 4. Levels of Urban Water Management Analysis

Preliminary: Print out information from Nationwide Assessment (157)

Level I: Desktop - no computer, statistical analysis

- UF Methodology (153)
- Hydroscience methodology (R-8)

Level II: Simplified continuous simulation model

- Simplified SWMM (by M&E) (148)

Level III: Refined continuous simulation model

- Continuous SWMM (P-53)
- STORM (R-9, R-10)

Level IV: Sophisticated single event simulation model

- Detailed SWMM (116,125)

## Planning/Design Models

### Level I--

The Level I procedure as developed by the University of Florida (153) was directly derived from the previously mentioned nationwide cost assessment project (157). This assessment document already contains data on land use; drainage system types; runoff volumes and pollutant quantities; costs and cost-effective control strategies for the 248 Standard Metropolitan Statistical Areas in the country. The information, also itemized for States and EPA regions, can be used in the early stages of problem assessment, determining national cost requirements and preliminary planning.

In Level I, a "desktop" statistical analysis procedure permits the user to estimate the quantity and quality of urban runoff in the combined, storm and unsewered portions of each urban area in his jurisdiction.

For example, under the University of Florida approach, equations such as those shown in Table 5. have been statistically developed to estimate BOD$_5$, SS, VS, PO$_4$ and N loads as a function of land use, type of sewer system, precipitation, population density, and street sweeping frequency. The $\alpha$ and $\beta$ terms represent normalized loading factors in lb/ac-in. tabularized as functions of land use, i and pollutant type, j, for separate and combined areas, respectively. These factors were derived from a statistical review of available stormwater pollutant loading and effluent concentration data (157).

Similarly, Table 6. gives equations for analyzing runoff for both stormwater flow prediction and DWF prediction. Here again the equations were based on a statistical analysis of available data.

## Table 5. Pollutant Analysis

The following equations may be used to predict annual average loading rates as a function of land use, precipitation and population density.

*Separate Areas:* $M_s = \alpha(i,j) \cdot P \cdot f_2(PD_d) \cdot \gamma \ \frac{\text{lb}}{\text{acre-yr}}$

*Combined Areas:* $M_c = \beta(i,j) \cdot P \cdot f_2(PD_d) \cdot \gamma \ \frac{\text{lb}}{\text{acre-yr}}$

where
$M$ = pounds of pollutant $j$ generated per acre of land use $i$ per year,
$P$ = annual precipitation, inches per year,
$PD_d$ = developed population density, persons per acre,
$\alpha, \beta$ = factors given in table below,
$\gamma$ = street sweeping effectiveness factor, and
$f_2(PD_d)$ = population density function.

*Land Uses:*
$i = 1$ Residential
$i = 2$ Commercial
$i = 3$ Industrial
$i = 4$ Other Developed, e.g., parks, cemeteries, schools (assume $PD_d = 0$)

*Pollutants:*
$j = 1$ $BOD_5$, Total
$j = 2$ Suspended Solids (SS)
$j = 3$ Volatile Solids, Total (VS)
$j = 4$ Total $PO_4$ (as $PO_4$)
$j = 5$ Total N

*Population Function:*
$i = 1$ $f_2(PD_d) = 0.142 + 0.218 \cdot PD_d^{0.54}$
$i = 2,3$ $f_2(PD_d) = 1.0$
$i = 4$ $f_2(PD_d) = 0.142$

*Factors α and β for Equations:* Separate factors, $\alpha$, and combined factors, $\beta$, have units lb/acre-in. To convert to kg/ha-cm, multiply by 0.442.

| | | Pollutant, j | | | | |
|---|---|---|---|---|---|---|
| | Land Use, i | 1. $BOD_5$ | 2. SS | 3. VS | 4. $PO_4$ | 5. N |
| Separate Areas, α | 1. Residential | 0.799 | 16.3 | 9.45 | 0.0336 | 0.131 |
| | 2. Commercial | 3.20 | 22.2 | 14.0 | 0.0757 | 0.296 |
| | 3. Industrial | 1.21 | 29.1 | 14.3 | 0.0705 | 0.277 |
| | 4. Other | 0.113 | 2.70 | 2.6 | 0.00994 | 0.0605 |
| Combined Areas, β | 1. Residential | 3.29 | 67.2 | 38.9 | 0.139 | 0.540 |
| | 2. Commercial | 13.2 | 91.8 | 57.9 | 0.312 | 1.22 |
| | 3. Industrial | 5.00 | 120.0 | 59.2 | 0.291 | 1.14 |
| | 4. Other | 0.467 | 11.1 | 10.8 | 0.0411 | 0.250 |

*Street Sweeping:* Factor $\gamma$ is a function of street sweeping interval, $N_s$, (days):

$$\gamma = \begin{cases} N_s/20 & \text{if } 0 \le N_s \le 20 \text{ days} \\ 1.0 & \text{if } N_s > 20 \text{ days} \end{cases}$$

Table 6. Runoff Analysis

Stormwater Flow Prediction

$$AR = (0.15 + 0.75\ I/100)\ P - 5.234\ (DS)^{0.5957}$$

where $AR$ = Annual Runoff, in/yr

$$I = 9.6\ PD_d^{(0.573-0.0391\ \log_{10}PD_d)}$$

where $I$ = Imperviousness, Percent and

$PD_d$ = Population Density in Developed Portion of the Urbanized Area, Persons/Acre

$P$ = Annual Precipitation, in/yr and

$$DS = 0.25-0.1875\ (I/100) \quad 0 \leq I \leq 100$$

where $DS$ = Depression Storage, in. $(0.005 \leq DS \leq 0.30)$

Dry Weather Flow Prediction

$$DWF = 1.34\ PD_d$$

where $DWF$ = Annual Dry-Weather Flow, in/yr, and

$PD_d$ = Developed Population Density, Persons/Acre

A generalized method for evaluating the optimal mix of storage and treatment and its associated costs has also been developed. Also, procedures for comparing tertiary treatment with stormwater management and possible savings from integrated management of domestic wastewater, stormwater quality and stormwater quantity from combined and separate drainage areas, are available.

The Hydroscience approach offers another procedure for assessing urban pollutant sources, loadings, and control. Both approaches, available in the form of user's manuals, are at press (153, R-8).

Level II--

Level II involves a simplified continuous model for planning and preliminary sizing of facilities. The model can run on daily time steps to screen the entire history of rainfall records or hourly time steps to screen the worst two years. It is inexpensive to set up and use, flexible enough to be applicable to a variety of system configurations, and accurate even though only very moderate expenditures are made for data collection and preparation. It is especially valuable in sizing storage facilities based on storm return periods and available in-line capacity. A user's manual is available (148).

Level III--

Level III involves a more refined continuous model approach (e.g., STORM, continuous SWMM) which in addition to Level II provides for flow time routing and continuous receiving water impact analyses. The number of program statements involved here is in the order of a few thousand as compared to a few hundred for the Level II effort. A user's manual and program for STORM is available (R-9, R-10). The continuous SWMM user's manual is in preparation; however, the computer program is available from the University of Florida.

Level IV--

The aforementioned three levels essentially represent various degrees of planning efforts and the models involved are typified by relatively large time steps (hours) and long simulation times (months and years). Data requirements are kept to a minimum and their mathematical complexity is low.

Design models on the other hand are oriented toward the detailed simulation of a single storm event. They provide a complete description of flow and pollutant routing from the point of rainfall through the entire urban runoff system and into the receiving waters. Such models may be used for predictions of flows and concentrations anywhere in the rainfall-runoff system and can illustrate the detailed and exact manner in which abatement procedures or design options affect them. As such, these models are a highly useful tool for determining least-cost abatement procedures for both quantity and quality problems in urban areas. They are typified by short time steps (minutes) and short simulation times (hours). Data requirements are usually very extensive. The EPA SWMM is such a model. SWMM user's manuals and other pertinent references that were revised at critical junctures are available (42,43,44,45,116,120). The Program would like to end the simulation modeling program by expanding SWMM into an Urban Water Management Model which integrates both dry- and wet-weather flow analyses including sludge handling capabilities. This is emphasized in the Program report on future direction of the modeling development (136).

## Operational Models

There is also a defined program for operational models. Operational models are used to produce actual control decisions during a storm event. Rainfall is entered from telemetered stations and the model is used to predict system responses a short time into the future. Various control options may then be employed, e.g., in-system storage, diversions, regulator settings. The Program has demonstrated supervisory control models in Detroit (118), Minneapolis-St. Paul (19), and Seattle (29,98); and have recently started on a program in San Francisco (P-25) riding "piggy-back" with a $100 million construction grant, to develop a fully automated operational model which includes rainfall prediction.

## Simulation Models: Products

Other simulation model products include demonstration of a dissemination and user assistance capability (122) and development of a short course and course manual (125, P-51) for stormwater management model application. Of particular note is the SOTA assessment document on 18 available mathematical models for storm and combined sewer management (141). The document presents a summary of the objectives, advantages and limitations of each model along with a side-by-side comparison to aid in assessing the applicability of a model for a particular purpose. Table 7. summarizes simulation model products.

Table 7. Simulation Models: Products

- Development of a computer model (SWMM) for storm water management (42,43,44,45).
- Updated and refined user's manual modifying and improving SWMM (116).
- Demonstration of a stormwater management model dissemination and user assistance capability (122).
- User's manual for "desk-top calculation" procedure for preliminary stormwater management planning (153).
- User's manual for simplified model application for preliminary stormwater management planning (148).
- Course manual and seminar for stormwater management model application (125).
- Assessment of mathematical models for storm and combined sewer management (141).
- Refine and augment the capabilities of SWMM and develop decision-making capabilities (120).
- Evaluation of available runoff prediction methods for storm flowrate and volume determination (140).

# MANAGEMENT ALTERNATIVES

Wet weather flow control can be grouped into three management alternatives. First there is the choice as to where to attack the problem: at the source, (e.g., the street, gutters, and catchment areas) by land management, in the collection system, or off-line by storage. Pollutants can be removed by treatment and by employing complex or integrated systems which combine variations of control and treatment including the dual-use of dry-weather facilities. Second, there is the choice of how much control or degree of treatment to introduce. Thirdly, there is the impact assessment, public exposure, and priority ranking with other needs. The proper management alternatives can only be made after a cost-effective analysis involving goals; values; and hydrologic-physical system evaluations, generally assisted by mathematical model simulations, pilot-scale trials, and new technology transfer.

## LAND MANAGEMENT

Land Management includes all measures for reducing urban and construction site stormwater runoff and pollutants before they enter the downstream drainage system (Figure 13). On-site measures include structural, semi-structural and non-structural techniques that affect both the quantity and quality of runoff.

Careful consideration must be given to land use planning since urbanization accelerates hydrograph and pollutograph peaks and total loads by creating impervious surfaces for pollutants and water to run off from. This causes excessive water pollution, erosion, sedimentation and flooding. Discreet selection of land management techniques can reduce drainage and other downstream control costs associated with these problems.

Until two important philosophies prevail, the high cost implications for wet-weather pollution abatement will continue. Established flood and erosion control technology must be integrated with pollution control technology so that the retention and drainage facilities and other non-structural management techniques required for flood and erosion control can be simultaneously designed for pollution control.

### Structural/Semi-Structural Control

Structural and semi-structural control measures require physical modifications in a construction or urbanizing area and includes such techniques as: on-site storage, porous pavement, overland flow modifications and solids separation.

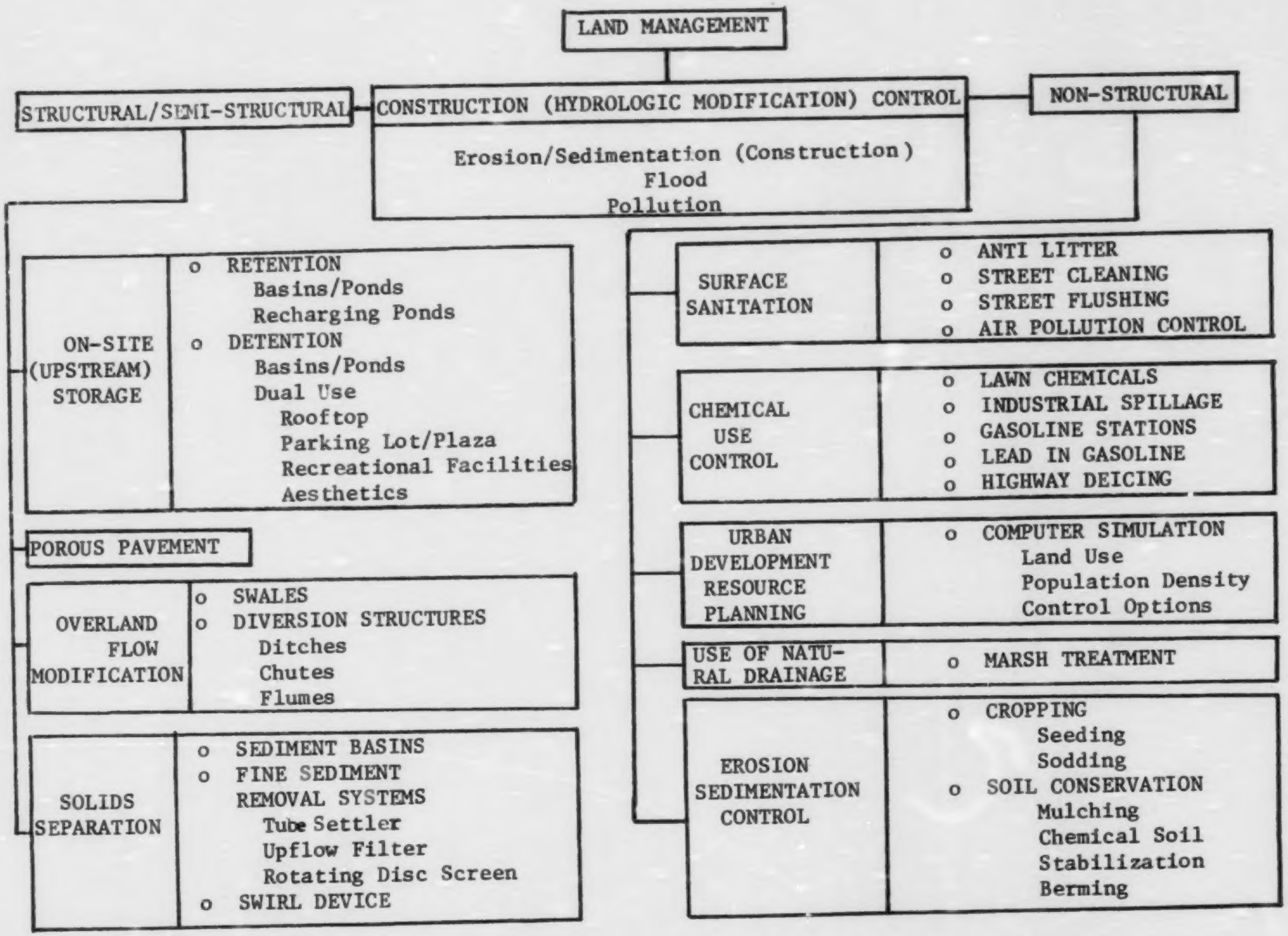

LAND MANAGEMENT
STRUCTURAL/SEMI-STRUCTURAL
CONSTRUCTION (HYDROLOGIC MODIFICATION) CONTROL
Erosion/Sedimentation (Construction)
Flood
Pollution
NON-STRUCTURAL
ON-SITE (UPSTREAM) STORAGE
o RETENTION
Basins/Ponds
Recharging Ponds
o DETENTION
Basins/Ponds
Dual Use
Rooftop
Parking Lot/Plaza
Recreational Facilities
Aesthetics
POROUS PAVEMENT
OVERLAND FLOW MODIFICATION
o SWALES
o DIVERSION STRUCTURES
Ditches
Chutes
Flumes
SOLIDS SEPARATION
o SEDIMENT BASINS
o FINE SEDIMENT REMOVAL SYSTEMS
Tube Settler
Upflow Filter
Rotating Disc Screen
o SWIRL DEVICE
SURFACE SANITATION
o ANTI LITTER
o STREET CLEANING
o STREET FLUSHING
o AIR POLLUTION CONTROL
CHEMICAL USE CONTROL
o LAWN CHEMICALS
o INDUSTRIAL SPILLAGE
o GASOLINE STATIONS
o LEAD IN GASOLINE
o HIGHWAY DEICING
URBAN DEVELOPMENT RESOURCE PLANNING
o COMPUTER SIMULATION
Land Use
Population Density
Control Options
USE OF NATURAL DRAINAGE
o MARSH TREATMENT
EROSION SEDIMENTATION CONTROL
o CROPPING
Seeding
Sodding
o SOIL CONSERVATION
Mulching
Chemical Soil Stabilization
Berming

Figure 13. Land Management

### On-Site (Upstream) Storage--

On-site or upstream storage refers to detention (short term) or retention (long term) of runoff prior to its entry into a drainage system. Simple ponding techniques are utilized on open areas where stormwater can be accumulated without damage or interference to essential activities. Oftentimes, on-site storage does or can be designed to provide for the dual or multi-benefits of aesthetics, recreation, recharge, irrigation, or other uses. For example, in Long Island, NY, groundwater supplies are being replenished by retention-recharge. The dual benefit of recharging is stressed because urbanization depletes groundwater supplies; however, potential groundwater pollution must also be considered.

Successful variations of detention that take advantage of facilities primarily used for other purposes are ponding on parking lots, plazas, recreation and park areas; and ponding on roof tops. The fundamental approach is the same as for other forms of detention but low cost is implied. Dual purpose basins used for recreation and athletics when dry are also employed.

Surface ponding is the most common form of detention being used by developers. Apparent economic benefits of surface ponding for flood protection are derived from the savings over a conventional sewer project. Several surface ponding sites are listed in Table 8. where a cost comparison is made between a drainage system using surface ponds to decrease peak flows and a conventional storm sewer system. It is important to note that pollution and erosion control benefits of the basins are not included in this comparison.

Table 8. Cost Comparison Between Surface Ponding Techniques and Conventional Sewer Installation (R-8).

| Site | Description | Cost estimate, $ | |
|---|---|---|---|
| | | With surface ponding | With Conventional sewers |
| Earth City, Missouri | A planned community including permanent recreational lakes with additional capacity for storm flow | 2,000,000 | 5,000,000 |
| Consolidated Freightways, St. Louis, Missouri | A trucking terminal using its parking lots to detain storm flows | 115,000 | 150,000 |
| Ft. Campbell, Kentucky | A military installation using ponds to decrease the required drainage pipe sizes | 2,000,000 | 3,370,000 |
| Indian Lakes Estates, Bloomington, Illinois | A residential development using ponds and an existing small diameter drain | 200,000 | 600,000 |

Porous Pavement--

Another approach to stormwater management is the use of an open graded asphalt-concrete pavement which under pilot testing has allowed over 70 in./hr of stormwater to flow through (Figure 14.) (64). Stability, durability, and freeze-thaw tests have been positive and it is comparable in cost to conventional pavement. Long-term tests are still required to evaluate clogging resistance and the quality of water that filters through. If the soil porosity under the pavement allows free drainage there will be no water residue; however, the coarse sub-base and porous nature of the pavement can serve for ponding capacity if storm quantities exceed soil infiltration. A 4-inch pavement and 6-inch base could store 2.4 in. of runoff volume in its voids. The proven use of porous pavement can be an important tool in preserving natural drainage and decreasing downstream drainage and pollution control facility requirements. As a result of Program studies a feasibility report (64) is available. The Program is currently evaluating a porous pavement parking lot (P-16) and results of this study will be available next year.

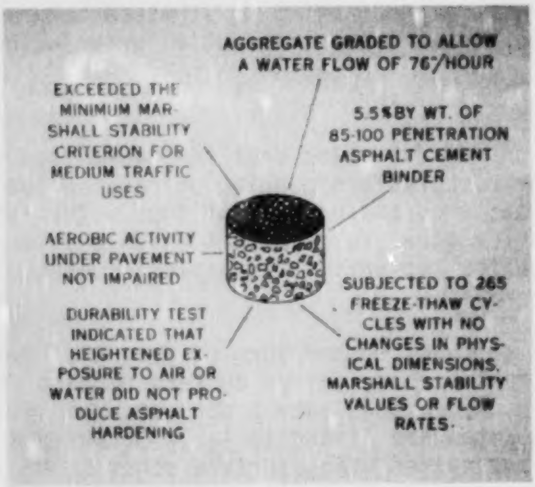

AGGREGATE GRADED TO ALLOW A WATER FLOW OF 76"/HOUR
EXCEEDED THE MINIMUM MARSHALL STABILITY CRITERION FOR MEDIUM TRAFFIC USES
5.5% BY WT. OF 85-100 PENETRATION ASPHALT CEMENT BINDER
AEROBIC ACTIVITY UNDER PAVEMENT NOT IMPAIRED
SUBJECTED TO 265 FREEZE-THAW CYCLES WITH NO CHANGES IN PHYSICAL DIMENSIONS, MARSHALL STABILITY VALUES OR FLOW RATES.
DURABILITY TEST INDICATED THAT HEIGHTENED EXPOSURE TO AIR OR WATER DID NOT PRODUCE ASPHALT HARDENING

Figure 14. Porous Asphaltic-Concrete Features

Overland Flow Modification--

Another form of structural and semi-structural control is overland flow modification including swales and diversion structures (e.g., ditches, chutes, flumes). These modifications are usually of lower cost than subterranean sewer construction and importantly allow vegetative cover and soil infiltration to reduce runoff and pollutant loadings.

### Solids Separation--

Sediment basins trap and store sediment from erodible areas in order to conserve land and prevent excessive siltation downstream. If designed properly, these basins can remain after construction for on-site storage. A project (P-46) is evaluating the efficiency of sediment basins.

Because a significant portion of the eroded solids may be colloidal or unsettleable and therefore cannot be treated in conventional sedimentation basins, special devices for fine-particle removal are required. An ongoing project (P-73) has developed a SOTA (163) on methods for fine-particle removal and is now undertaking the evaluation of three solids separation devices (i.e., tube settler, up-flow filter, and rotating disc screen).

The swirl concentrator has been developed for erosion control (P-3, 99) to remove settleable solids at much higher rates than sedimentation. A prototype device is presently being evaluated at a construction site (P-74).

## Non-Structural

Non-Structural control measures involve surface sanitation, chemical use control, urban development resource planning, use of natural drainage, and certain erosion/sedimentation control practices (Figure 13.).

### Surface Sanitation--

Maintaining and cleaning the urban area can have a significant impact on the quantity of pollutants washed off by stormwater. Cleanliness starts with reduction of litter and debris at the neighborhood level. Both street repair and street sweeping can further minimize the pollutants washed off. It has been estimated that street sweeping costs per ton of solids removed are about half the costs for solids removed via the sewerage system.

The effectiveness of street sweeping operations with respect to stormwater pollution has been analyzed by EPA (73,88,128,157,P-49). It was found that a great portion of the overall pollution potential is associated with the fine solids fraction of the street surface contaminants and that only 50 percent of the dry weight solids are picked up by conventional broom sweepers (73) as compared to 93 percent removal by more advanced techniques (128) (Table 9.).

Table 9. Advanced* Street Cleaner Pollutant Recovery Percentage

| Parameter | % Recovery |
|---|---|
| Dry Weight Solids | 93 |
| Volatile Solids | 80 |
| BOD | 67 |
| COD | 84 |
| Total $PO_4$-P | 85 |
| Heavy Metals | 83-98 |

*Broom and Vacuum Combination

Cities clean their streets for aesthetic reasons, removing the larger particles and brushing aside the fines. Conventional sweepers are utilized and satisfy the aesthetics problem. More advanced street cleaning procedures such as a combination of sweeping and vacuuming would not only satisfy the aesthetics problem but would also attack the source of stormwater related pollution problems by removing the finer or more pollutant prone range of particles.

Further verification of the benefits of street cleaning will be carried out in an ongoing grant (P-25). Also, a desk-top analysis comparing the cost-effectiveness of street cleaning and sewer flushing with downstream treatment methods is nearing completion under another study (P-73). Flushing of streets can be used to remove street contaminants effectively; however, it may necessitate more frequent catch basins and sewer cleaning. Street cleaning is estimated to cost $3 to $13/curb mi or about $0.75/ac.

Air pollution abatement plans must also consider water pollution reduction benefits from decreased fall out.

Chemical Use Control--

One of the most overlooked measures for reducing the pollution potential from neighborhood areas is the reduction in the indiscriminate use of chemicals such as fertilizers and pesticides, and the mishandling of other materials such as oil, gasoline, and highway deicing chemicals. Aside from air pollution control, de-leaded gasoline also results in water pollution control.

The progression of studies in deicing chemical control, and resulting reports, is depicted in Figure 15. The Program's motivation from the start has been to determine the extent of environmental damages and costs associated with the use of chemical deicers so that the economic validity of alternative approaches could be assessed.

Until the Program's assessment of the problem in 1971 (67) there had been only limited research on highway deicing effects. Inquiries concerning this work indicated such an increased public awareness of the salt problems, that it seemed appropriate to firm up recommendations for alternatives to snow and ice control. A search was conducted (76) to define alternatives. The need for an accurate economic impact analysis of using deicing salt, and a requirement to identify a substance which can be applied to pavement to reduce ice adhesion was indicated. These two needs became projects which have recently been completed (138,152). Hydrophobic substances have been identified and are being investigated, and even though material and application costs appear greater than for salt (0.20-0.25/yd$^2$ vs. $0.03/yd$^2$), when considering total damage to the environment ($3 billion annually, including paved area, highway structures and vehicles) the costs are acceptable.

After the 1973 assessment of the problem (86,R-11), the Program recognized that it was not practical to ban salt since the "bare pavement" philosophy was very popular and considered by most highway authorities as the safest way for ice and snow removal. The major problems were identified

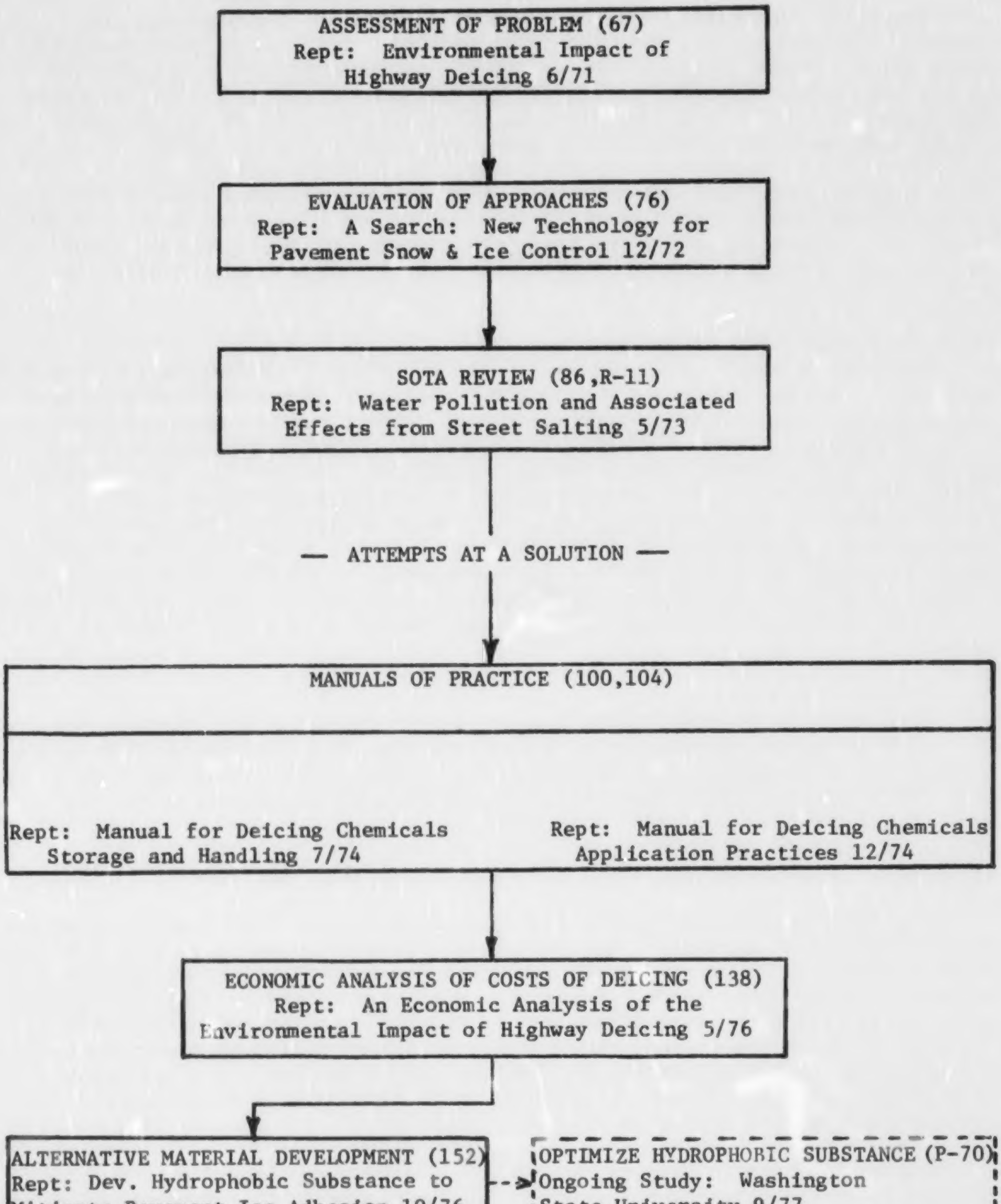

ASSESSMENT OF PROBLEM (67)
Rept: Environmental Impact of Highway Deicing 6/71
EVALUATION OF APPROACHES (76)
Rept: A Search: New Technology for Pavement Snow & Ice Control 12/72
SOTA REVIEW (86,R-11)
Rept: Water Pollution and Associated Effects from Street Salting 5/73
— ATTEMPTS AT A SOLUTION —
MANUALS OF PRACTICE (100,104)
Rept: Manual for Deicing Chemicals Storage and Handling 7/74
Rept: Manual for Deicing Chemicals Application Practices 12/74
ECONOMIC ANALYSIS OF COSTS OF DEICING (138)
Rept: An Economic Analysis of the Environmental Impact of Highway Deicing 5/76
ALTERNATIVE MATERIAL DEVELOPMENT (152)
Rept: Dev. Hydrophobic Substance to Mitigate Pavement Ice Adhesion 10/76
OPTIMIZE HYDROPHOBIC SUBSTANCE (P-70)
Ongoing Study: Washington State University 9/77

Figure 15. Deicing Chemical Control (Land Management/Non-Structural)

with sloppy salt storage practices and over-application on highways, consequently, a 1974 project resulted in manuals of practice for improvement in these areas. These manuals (100,104) were recognized as highly significant by the user community and the Federal Highway Administration (FHWA) requested permission to reprint them for their own distribution. To date, over 7000 copies have been distributed to the user community.

It is believed that the outcome of EPA work has prompted several states to enact legislation controlling the application and storage of salt. In the future it is hoped to verify the cost-effectiveness of the hydrophobic substances both through research of R&D (P-70) and in a joint effort with the FHWA.

Urban Development Resource Planning--

The goal of urban development resource planning is to develop a macroscopic management concept to prevent the problems resulting from shortsighted urbanization plans. As previously discussed, the planner must be aware of totally integrating planned urban hydrology with erosion-sedimentation and pollution control. This new breed of planner has to consider the new land development planning variables of land usage, population density and total wet and dry runoff control as they integrate to effect water pollution. Computer simulation will most likely play an important role. A simple land planning model has been developed by G.K. Young (140a, Chapter I, pp 98-121) to encompass the pertinent variables and the most effective control options based upon receiving water pollutant absorption capacity. A new project is planned to perfect this area.

Use of Natural Drainage--

The traditional urbanization process upsets the existing water balance of a site by replacing natural infiltration areas and drainage with impervious areas. The net impact is increased runoff, decreased infiltration to the groundwater and increased flowrates, all contributing to increased channel erosion and the transport of surface pollutants to the stream. Promulgating the use of natural drainage concepts will reduce drainage costs; enhance aesthetics, groundwater supplies, and flood protection; and lower pollution.

A project in Houston (P-16) focuses on how a "natural drainage system" can be integrated into a reuse scheme for recreation and aesthetics. Good land use management will allow runoff to flow through low vegetated swales and into a network of wet-weather ponds, strategically located in areas of porous soils. This system will cause some of the runoff to seep into the ground and retard the flow of water downstream, thus preventing floods caused by development and enhancing pollution abatement. The concept of considering urban runoff as a benefit as opposed to a wastewater, in a new community development, will be employed and evaluated.

Another project in Wayzata, MN (P-28) is using marshland for stormwater treatment. After sufficient testing it has been determined that controlled stormwater retention in the marsh resulted in better vegetative conditions which in turn enhanced stormwater nutrient removal. It was found that if the marshlands were filled in by urbanization it would have a detrimental effect on the nearby Lake.

Erosion/Sedimentation Control (Non-Structural)--

Other nonstructural soil conservation practices such as cropping (seeding and sodding) and the use of mulch blankets, nettings, chemical soil stabilizers and berming may be relatively inexpensive. Two ongoing projects (P-72, P-74) are evaluating many of these low structural intensive management practices for proposed erosion control manuals.

## Integrated Benefits

While the flood control benefits of all the above land management control measures are easy to see, the stormwater pollution and erosion control effects are difficult to quantify. But briefly stated, detaining or retaining flow upstream offers the opportunity for flow quiescence resulting in solids separation. It also decreases downstream drainage velocities and discharges to streams resulting in less overflow pollution, siltation and scour. Aside from causing downstream erosion, this scouring can also increase pollution loads in the scouring stream.

## Erosion/Sediment Control: Products

By showing the genealogy of the products through past milestone events (Figure 16.) the strategy which has guided the Program in this category can be demonstrated. The original "Guidelines for Erosion and Sediment Control Planning and Implementation" (70) are still applicable to communities initiating an urban sediment control program.

For erosion-sedimentation controls, many agencies (e.g., The Department of Transportation and Soil Conservation Service, and state and local departments) and factors must be considered and interrelated in product development and technology implementation. For example, the Soil Conservation Service has published a document with the State of Maryland entitled "Standards and Specifications for Soil Erosion and Sediment Control in Developing Areas" (R-12). Other states are using this document as a model ordinance. Local laws will have an important impact on any Best Management Practices proposed by EPA. Therefore, there must be close liaison between all groups.

A recently developed training program consists of an instructor's manual (168), a workbook (169), and 2762 slides with integrated audio cassettes. The program is directed to the local land developer and inspector, the excavation contractor, and the job foreman. It is designed to directly support the Maryland "Standards and Specifications for Erosion and Sediment Control in Developing Areas." As the state and local agencies move toward setting standards for control on non-point sources, the need for this type of training program becomes urgent.

Future Program plans include an evaluation of various cities' erosion control programs. This product will be the foundation for National Standards and Specifications for sediment and erosion control in developing areas and with the findings of the Urban Runoff Program will lead to the National Best Management Practice for this category.

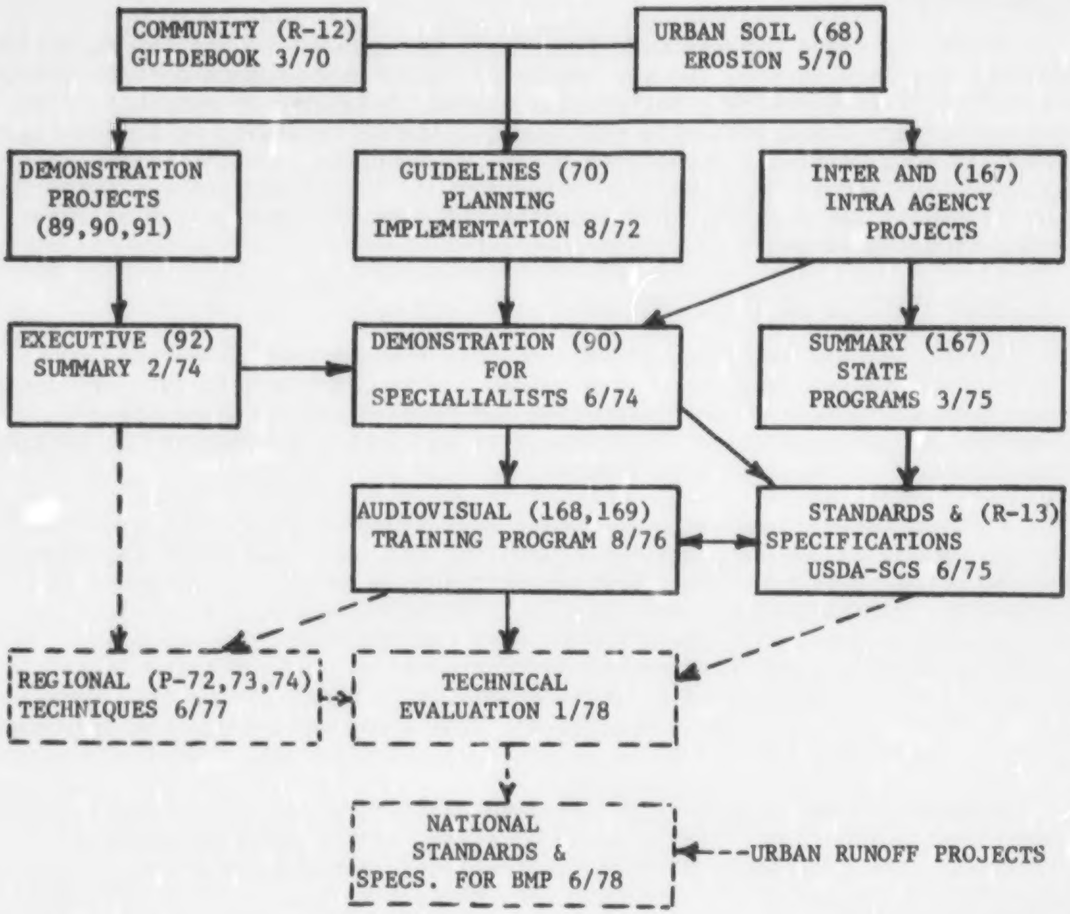

COMMUNITY (R-12) GUIDEBOOK 3/70
URBAN SOIL (68) EROSION 5/70
DEMONSTRATION PROJECTS (89,90,91)
GUIDELINES (70) PLANNING IMPLEMENTATION 8/72
INTER AND (167) INTRA AGENCY PROJECTS
EXECUTIVE (92) SUMMARY 2/74
DEMONSTRATION (90) FOR SPECIALIALISTS 6/74
SUMMARY (167) STATE PROGRAMS 3/75
AUDIOVISUAL (168,169) TRAINING PROGRAM 8/76
STANDARDS & (R-13) SPECIFICATIONS USDA-SCS 6/75
REGIONAL (P-72,73,74) TECHNIQUES 6/77
TECHNICAL EVALUATION 1/78
NATIONAL STANDARDS & SPECS. FOR BMP 6/78
URBAN RUNOFF PROJECTS

Figure 16. Erosion/Sedimentation Control: Products

## Hydrologic Modification Category Status

It is important to discuss the status of the Hydrologic Modification Program category.

The product "Impact of Hydrologic Modification on Water Quality" (129) describes the scope and magnitude of water pollution and flood and erosion-sediment problems caused by hydrologic modifications such as dams, impoundments, channelization, in-water construction, out-of-water construction, land reclamation, and dredging. It is an excellent overview document.

There are important administrative decisions affecting this category.

1. The out-of-water construction element is no longer part of this category. It is the construction site erosion-sedimentation category previously defined.
2. There has been an interagency agreement assigning the U.S. Army Corps of Engineers the function of dredging impacts and control.
3. The R&D activities for land reclamation are mainly conducted by other EPA offices (e.g., beach reclamation in the Office of Oil and Special Materials Control Branch and strip mine reclamation in the Office of Energy, Minerals, and Industry).

The Program strategy is to allocate most of the resources to urban runoff and then to construction.

## COLLECTION SYSTEM CONTROLS

The next category, collection system control (Figure 17.), pertains to those management alternatives concerned with wastewater interception and transport. These alternatives include sewer separation; improved maintenance and design of catch basins, sewers, regulators and tide gates; and remote flow monitoring and control. The emphasis, with the exception of sewer separation, is on optimum utilization of existing facilities and fully automated control. Because added use of the existing system is employed, the concepts generally involve cost-effective, low-structurally intensive control alternatives. To accomplish this an extensive and dependable intelligence system is necessary.

### Catch Basins

A project is assessing the value of catch basins (P-17,174) as they are presently designed and maintained. Optimized basin configuration, design and maintenance for removing solids before sewerage system entry has also being investigated. Evaluations showed that a catch basin contains approximately 0.18 lb-$BOD_5$ or the equivalent of one person's daily contribution. Consequently, the utilization of catch basins (which depends on a city's network configuration and multi-agency desires) can either contribute to the pollutional load or aid in reducing downstream treatment depending on their design and maintenance. A full-scale demonstration of catch basin technology is recommended (p-17).

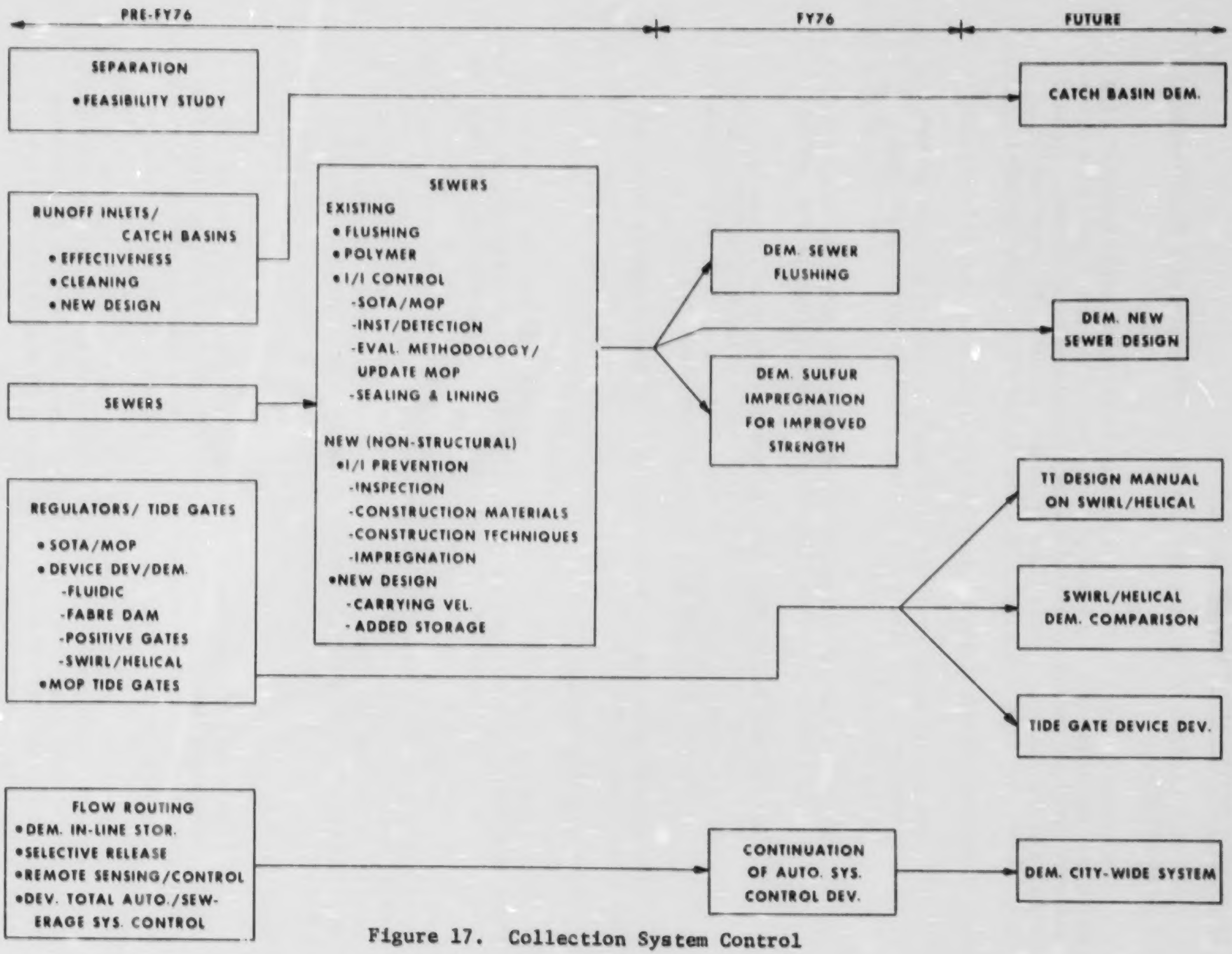

PRE-FY76
FY76
FUTURE
SEPARATION
•FEASIBILITY STUDY
RUNOFF INLETS/
CATCH BASINS
•EFFECTIVENESS
•CLEANING
•NEW DESIGN
SEWERS
REGULATORS/ TIDE GATES
•SOTA/MOP
•DEVICE DEV/DEM.
-FLUIDIC
-FABRE DAM
-POSITIVE GATES
-SWIRL/HELICAL
•MOP TIDE GATES
FLOW ROUTING
•DEM. IN-LINE STOR.
•SELECTIVE RELEASE
•REMOTE SENSING/CONTROL
•DEV. TOTAL AUTO./SEWERAGE SYS. CONTROL
SEWERS
EXISTING
•FLUSHING
•POLYMER
•I/I CONTROL
-SOTA/MOP
-INST/DETECTION
-EVAL. METHODOLOGY/
UPDATE MOP
-SEALING & LINING
NEW (NON-STRUCTURAL)
•I/I PREVENTION
-INSPECTION
-CONSTRUCTION MATERIALS
-CONSTRUCTION TECHNIQUES
-IMPREGNATION
•NEW DESIGN
-CARRYING VEL.
-ADDED STORAGE
DEM. SEWER FLUSHING
DEM. SULFUR IMPREGNATION FOR IMPROVED STRENGTH
CONTINUATION OF AUTO. SYS. CONTROL DEV.
CATCH BASIN DEM.
DEM. NEW SEWER DESIGN
TT DESIGN MANUAL ON SWIRL/HELICAL
SWIRL/HELICAL DEM. COMPARISON
TIDE GATE DEVICE DEV.
DEM. CITY-WIDE SYSTEM

Figure 17. Collection System Control

## Sewers

Solids deposition in lines has always been a plague to effective maintenance. Recently, the significance of such loads as a major contributor to first flush pollution has been recognized (P-66; 140a, Chapter II, pp 62-82).

Work is being conducted on new sewer designs for low flow solids carrying velocity to alleviate sewer sedimentation and resultant first flush and premature bypassing (P-50); and also on sewer designs for added storage (P-13,165). As a natural follow-up to Program work with a controlled test loop (13,14), a project has just been initiated to demonstrate periodic sewer flushing during dry weather for first flush relief (P-66).

### Polymers To Increase Capacity--

Research (6,11, P-6) has shown that polymeric injection can increase flow capacity as much as 2.4 times (at a constant head). This method can be used as a short or long-term correction of troublesome pollution-causing conditions such as localized flooding and excessive overflows. Direct cost savings may be realized by eliminating relief sewer construction (6); however, additional cost verification at the site is necessary.

### Infiltration/Inflow--

The Program SOTA (27) and manual of practice (MOP) (28) on infiltration/inflow (I/I) identified a significant problem which led to fruitful countermeasure research and a national emphasis on I/I control. Program developments have included detection methodology and instrumentation (27,28,10); preventive installation and construction techniques, new and improved materials (22,27,28, 52,61, P-31,P-41); and correction techniques (12). A project to update and develop practices for determining and correcting infiltration and its economic analysis (P-18,166) is nearing completion. An in-house paper on the analysis and evaluation of I/I has been published (R-14). Another project is evaluating the strength increases and erosion resistance, and resulting infiltration prevention from sulfur impregnation of concrete pipe (P-30,52). Since pipe costs are significant, an increase in strength could lead to a decrease in pipe materials and construction costs.

## Flow Routing

Another collection system control method is in-sewer or in-line storage and routing of storm flows to make maximum use of existing interceptors and sewer line capacity. The general approach comprises remote monitoring of rainfall, flow levels, and sometimes quality, at selected locations in the network, together with a centrally computerized console for positive regulation. This concept has proved to be effective in Minneapolis-St. Paul (19), Detroit (40,118), and Seattle (29,98). Seattle results are discussed later (Section 7, pp. 56-58) to indicate potential control and cost benefits.

An ongoing project mentioned earlier with the City of San Francisco is developing an automatic operational model for real-time control (P-25). Future demonstration of the system is anticipated.

## Regulators and Tide Gates

Program pace-setters in the area of flow regulator technology were the SOTA (23) and MOP (24).

Conventional regulators malfunction and cause excessive overflows. The new improved devices such as fluidic and positive control regulators have been developed and demonstrated (P-7,9,23,24,98,173). The swirl and helical regulator devices are significant enough to single out separately.

### Swirl and Helical Device Development--

The dual functioning swirl device has shown outstanding potential for providing both quality and quantity control (R-15,93).

A swirl flow regulator/solids-liquid separator has been demonstrated in Syracuse, NY (P-2; R-16; 140a, Chapter II, pp. 99-117). Figure 18. is an isometric review. The device, of simple annular shape construction, requires no moving parts. It provides a dual function, regulating flow by a central circular weir while simultaneously treating combined wastewater by a "swirl" action which imparts liquid-solids separation. The low-flow concentrate is diverted via a bottom orifice to the sanitary sewerage system for subsequent treatment at the municipal works, and the relatively clear supernatant overflows the weir into a central downshaft and receives further treatment or is discharged to the stream. The device is capable of functioning efficiently over a wide range (80:1) of combined sewer overflow rates, and can effectively separate suspended matter at a small fraction of the detention time required for conventional sedimentation or flotation (seconds to minutes as opposed to hours by conventional tanks). Tests indicate at least 50 percent removal of suspended solids and BOD. Tables 10. and 11. contain further treatability details on the Syracuse prototype. The capital cost of the 6.8 mgd Syracuse prototype was $55,000 or $8,100/mgd and $1,000/ac which makes the device highly cost-effective.

The swirl concept (for dual dry/wet-weather flow treatment) has been piloted as a degritter (P-71) in Denver, CO and as a primary clarifier in Toronto, Canada (P-71). Test results are very encouraging and the concept has been further developed for erosion control.

A helical or spiral-type regulator/separator has also been developed based on principles similar to those of the swirl device. The device is beneficial since its solids separation action is created by only a bend in the sewer line, and it is of relatively low depth.

Swirl and Helical: Products--Important products for this category are design manuals for the swirl (69,93,101) and helical (132) regulator/separators, swirl degritter (99) and swirl erosion control devices (151); and a Technology Transfer Capsule Report (162) which ties the various swirl applications together.

## Maintenance

Improved sewerage system inspection and maintenance is absolutely neces-

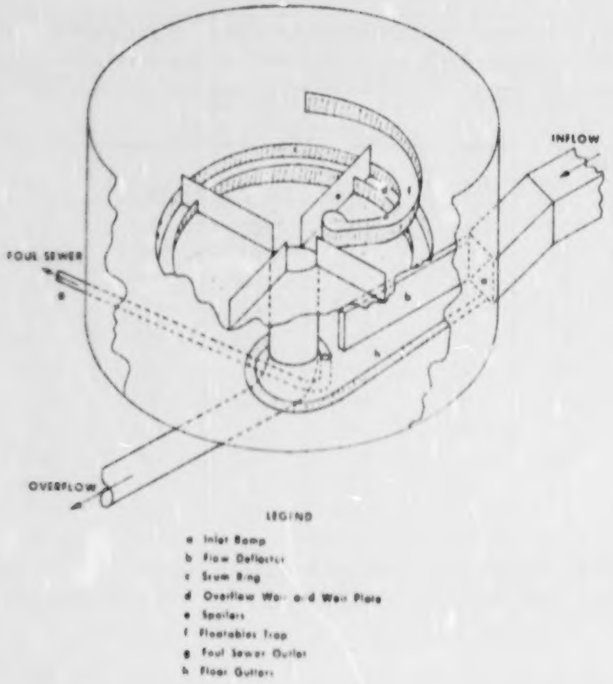

INFLOW
FOUL SEWER
g
b
h
OVERFLOW
LEGEND
a Inlet Ramp
b Flow Deflector
c Scum Ring
d Overflow Weir and Weir Plate
e Spoilers
f Floatables Trap
g Foul Sewer Outlet
h Floor Gutters

Figure 18. Isometric View of Swirl Regulator/Concentrator

sary for a total system approach to municipal water pollution control. We cannot afford the upgrading and proper operation of sewage treatment plants while a significant amount of sewage leaks into streams at the upstream points in the sewer network! Premature overflows and backwater intrusions during dry as well as wet weather caused by malfunctioning regulators and tide gates, improper diversion settings, and partially filled interceptors can thus be alleviated. Although the resulting abatement obtained is from a non-structural approach, it must be viewed as an ancillary benefit of required system maintenance. Regulatory agencies should be anxious to strive for policy to enforce collection system maintenance.

Table 10. Swirl Regulator/Concentrator: Suspended Solids Removal

| | Swirl Concentrator | | | | | | Conventional Regulator | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mass Loading kg | | | Average SS per storm, mg/l | | | Mass Loading kg | | |
| Storm No. | Inf. | Eff. | % Rem.[b] | Inf. | Eff. | % Rem.[b] | Inf. | Underflow | % Rem.[a] |
| 02-1974 | 374 | 179 | 52 | 535 | 345 | 36 | 374 | 101 | 27 |
| 03-1974 | 69 | 34 | 51 | 182 | 141 | 23 | 69 | 33 | 48 |
| 07-1974 | 93 | 61 | 34 | 110 | 90 | 18 | 93 | 20 | 22 |
| 10-1974 | 256 | 134 | 48 | 230 | 164 | 29 | 256 | 49 | 19 |
| 14-1974 | 99 | 57 | 42 | 159 | 123 | 23 | 99 | 26 | 26 |
| 01-1975 | 103 | 24 | 77 | 374 | 167 | 55 | 103 | 66 | 64 |
| 02-1975 | 463 | 167 | 64 | 342 | 202 | 41 | 463 | 170 | 34 |
| 06-1975 | 112 | 62 | 45 | 342 | 259 | 24 | 112 | 31 | 27 |
| 12-1975 | 250 | 168 | 33 | 291 | 232 | 20 | 250 | 48 | 19 |
| 14-1975 | 83 | 48 | 42 | 121 | 81 | 33 | 83 | 14 | 17 |
| 15-1975 | 117 | 21 | 82 | 115 | 55 | 52 | 117 | 72 | 61 |

[a] For the conventional regulator removal calculation, it is assumed that the SS concentration of the foul underflow equals the SS concentration of the inflow.

[b] Data reflecting negative SS removals at tail end of storms not included.

Table 11. Swirl Regulator/Concentrator: $BOD_5$ Removal

| | Mass Loading, kg | | | Average $BOD_5$ per storm, mg/l | | |
|---|---|---|---|---|---|---|
| Storm No. | Influent | Effluent | % Rem. | Inf. | Eff. | % Rem. |
| 7-1974 | 277 | 48 | 82 | 314 | 65 | 79 |
| 1-1975 | 97 | 30 | 69 | 165 | 112 | 32 |
| 2-1975 | 175 | 86 | 51 | 99 | 70 | 29 |

## STORAGE

Storage is perhaps the most cost-effective method available for reducing pollution resulting from combined sewer overflows and managing urban stormwater runoff. Furthermore, it is the best documented abatement measure in present practice. Program technological advancement for this category is depicted on Figure 19. (Storage with the resulting sedimentation that occurs, can also be thought of as a treatment process.)

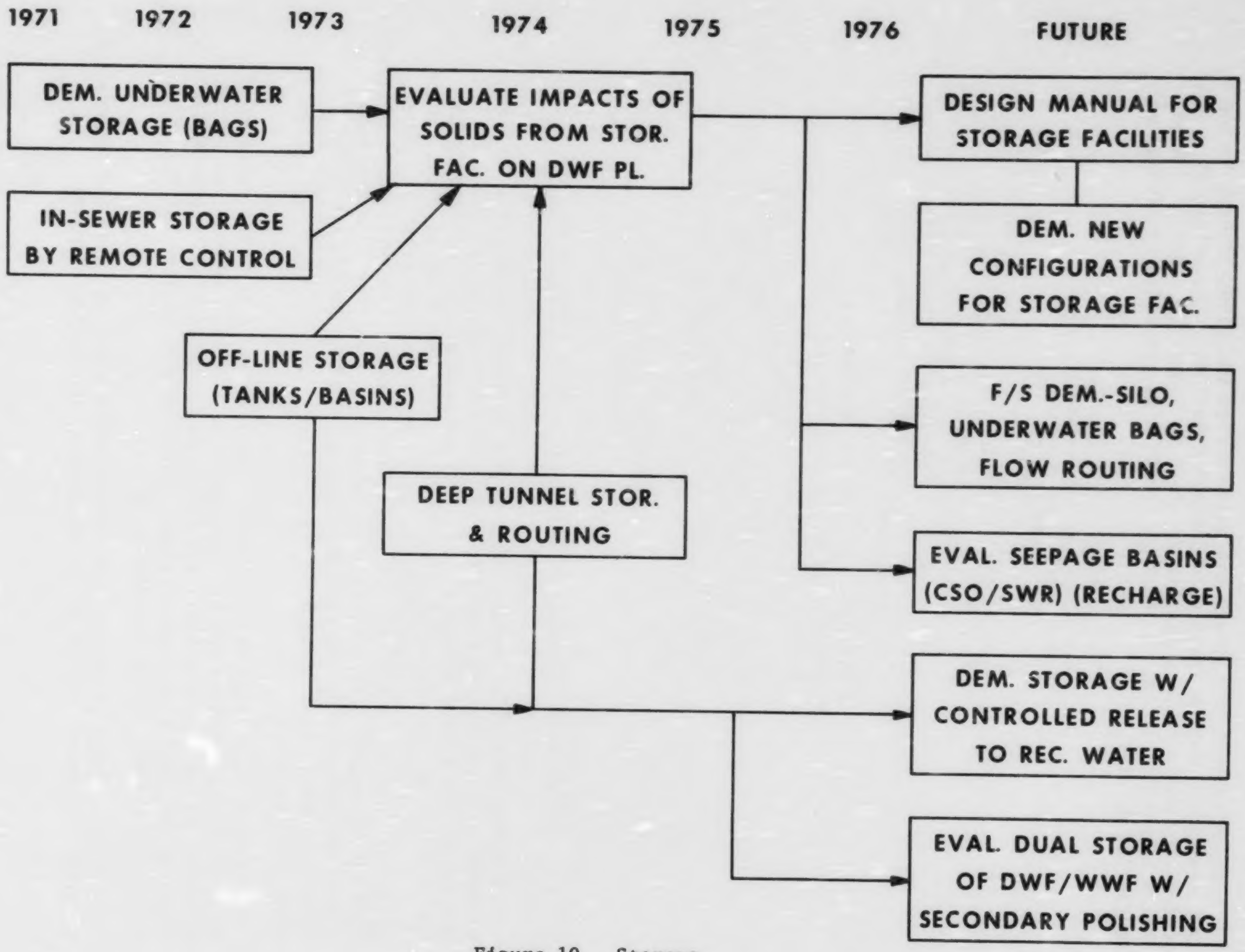

1971
1972
1973
1974
1975
1976
FUTURE
DEM. UNDERWATER STORAGE (BAGS)
IN-SEWER STORAGE BY REMOTE CONTROL
OFF-LINE STORAGE (TANKS/BASINS)
EVALUATE IMPACTS OF SOLIDS FROM STOR. FAC. ON DWF PL.
DEEP TUNNEL STOR. & ROUTING
DESIGN MANUAL FOR STORAGE FACILITIES
DEM. NEW CONFIGURATIONS FOR STORAGE FAC.
F/S DEM.-SILO, UNDERWATER BAGS, FLOW ROUTING
EVAL. SEEPAGE BASINS (CSO/SWR) (RECHARGE)
DEM. STORAGE W/ CONTROLLED RELEASE TO REC. WATER
EVAL. DUAL STORAGE OF DWF/WWF W/ SECONDARY POLISHING

Figure 19. Storage

The concept is to capture wet-weather flow and bleed it back to the treatment plant during low flow dry-weather periods. The result of controlling overflow by detention is shown on Figure 20. Notice how an entire hypothetical overflow event at point A is prevented by storage with controlled dewatering.

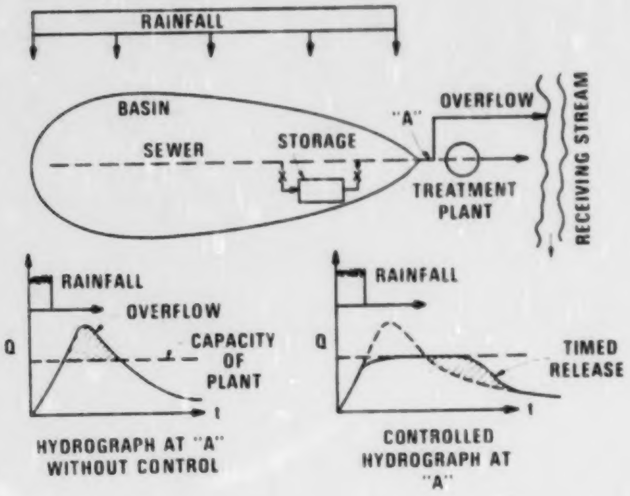

RAINFALL
BASIN
SEWER
STORAGE
"A"
OVERFLOW
TREATMENT PLANT
RECEIVING STREAM
RAINFALL
OVERFLOW
Q
CAPACITY OF PLANT
t
HYDROGRAPH AT "A" WITHOUT CONTROL
RAINFALL
Q
TIMED RELEASE
t
CONTROLLED HYDROGRAPH AT "A"

Figure 20. Results of Controlling Storm Flow by Storage

Storage facilities possess many of the favorable attributes desired in combined sewer overflow control: (1) they are basically simple in structural design and operation; (2) they respond without difficulty to intermittent and random storm behavior; (3) they are relatively unaffected by flow and quality changes; and (4) they are capable of providing flow equalization and, in the case of sewers and tunnels, transmission. (Frequently they can be operated in concert with regional dry-weather flow treatment plants for benefits during both dry- and wet-weather conditions (107).) Finally, storage facilities are relatively fail-safe and adapt well to stage construction.

Storage facilities may be constructed in-line or off-line; they may be open or closed; they may be constructed inland and upstream, or on the shoreline; they may have auxiliary functions, such as flood protection, sewer relief, and flow transmission. (And they may be used for hazardous spill containment during dry weather.)

Disadvantages of storage facilities are their large size and dependency on other treatment facilities for dewatering and solids disposal.

Storage concepts investigated by the program include the conventional concrete holding tanks (18,134) and earthen basins (30,72); and the minimun-land-requirement concepts of: tunnels (40), underground (85) and underwater containers (15,25,26), underground "silos (96)," gravel packed beds with overhead land use (154), natural (85) and mined under and above ground formations, and the use of abandoned facilities and existing sewer lines (19,29,98,118).

A 3.5 MG asphalt-lined storage basin in Chippewa Falls, WI (72) was constructed on reclaimed land and eliminated 59 out of 62 overflows during the evaluation period.

Inherent in many of these storage schemes is the pumping/bleeding back of the stored flow to the DWF plant during off-peak hours. The impacts of this increased load on the DWF plant (both from a hydraulic and increased solids point of view) is an important consideration and has been investigated in an ongoing project (159,161). Once this impact information is available, the SOTA on storage in the form of a design manual could be summarized.

The feasibility of off-line storage and deep tunnel storage along waterways for selective discharge based on least receiving water impacts is presently being investigated in Rochester, N.Y. (P-15). It is envisioned that this concept along with dual DWF/WWF storage, will be demonstrated in post FY 76 plans as part of a tie-in to construction grants.

Future Program plans include the investigation of new storage configurations, e.g., floating storage facilities, cofferdams, storage under piers, etc. Full-scale demonstration of some of the more promising configurations, such as silos and underwater bags, is also desirable.

## TREATMENT

Due to adverse and intense flow conditions and unpredictable shock loading effects, it has been difficult to adapt existing treatment methods to storm-generated overflows, especially the microorganism dependent biological processes. The newer physical/chemical treatment techniques have shown more promise in overcoming these adversities. To reduce capital investments, projects have been directed towards high-rate operations approaching maximum loading boundaries. Applications include pretreatment or roughing, main or sole treatment, and particularly with microstrainers and filters, polishing devices.

The various treatment methods which have been developed and demonstrated by the Program for storm flow include physical and physical-chemical, biological, and disinfection (Figure 21.). These processes, or combinations of these processes, can be adjuncts to the existing sanitary plant or serve as remote satellite facilities at the outfall.

### Physical/Chemical Treatment

Physical processes with or without chemicals, such as: fine screens (34,37,38,78,105), swirl primary separators (162, P-29) and swirl degritters (99,162,158, P-29), high-rate filters (35, P-39), sedimentation (36,81), and

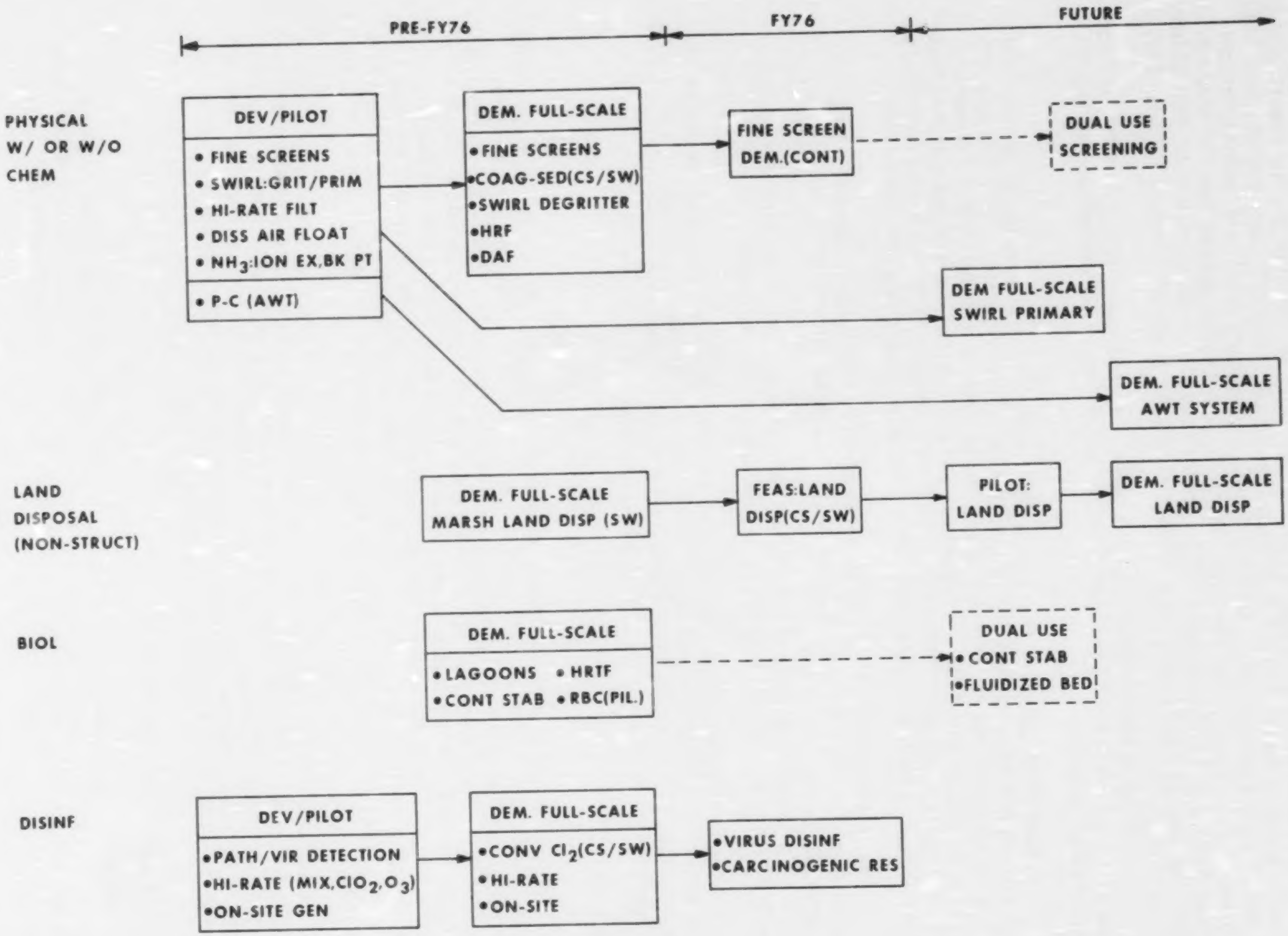

PRE-FY76
FY76
FUTURE
PHYSICAL W/ OR W/O CHEM
DEV/PILOT
• FINE SCREENS
• SWIRL:GRIT/PRIM
• HI-RATE FILT
• DISS AIR FLOAT
• NH3:ION EX,BK PT
• P-C (AWT)
DEM. FULL-SCALE
•FINE SCREENS
•COAG-SED(CS/SW)
•SWIRL DEGRITTER
•HRF
•DAF
FINE SCREEN DEM.(CONT)
DUAL USE SCREENING
DEM FULL-SCALE SWIRL PRIMARY
DEM. FULL-SCALE AWT SYSTEM
LAND DISPOSAL (NON-STRUCT)
DEM. FULL-SCALE MARSH LAND DISP (SW)
FEAS:LAND DISP(CS/SW)
PILOT: LAND DISP
DEM. FULL-SCALE LAND DISP
BIOL
DEM. FULL-SCALE
•LAGOONS •HRTF
•CONT STAB •RBC(PIL.)
DUAL USE
•CONT STAB
•FLUIDIZED BED
DISINF
DEV/PILOT
•PATH/VIR DETECTION
•HI-RATE (MIX,ClO2,O3)
•ON-SITE GEN
DEM. FULL-SCALE
•CONV Cl2(CS/SW)
•HI-RATE
•ON-SITE
•VIRUS DISINF
•CARCINOGENIC RES

Figure 21. Treatment

dissolved air flotation (20,21,131), have been developed and demonstrated by the Program. Ammonia removal (P-12 and advanced physical-chemical-adsorption systems (81) have also been developed and tested at the pilot level. Physical processes have shown importance for stormwater treatment because of their adaptability to automated operation, rapid startup and shut-down characteristics, high-rate operation, and very good resistance to shock loads.

This year an investment was made in a grant continuation (P-2) to further compare three different fine screens for combined sewer overflow treatment. In the near future the Program desires to implement a full-scale swirl primary treatment demonstration.

A microstrainer is conventionally designed for polishing secondary sewage plant effluent at an optimum rate of approximately 10 gpm/sq ft. Tests on a pilot microscreening unit of 23 micron aperture in Philadelphia have shown that at high influx rates of 25-30 gpm/sq ft, suspended solids removals in combined overflows as high as 90% can be achieved (34,78,105).

A study in Cleveland (35) showed high potential for treating combined sewer overflows by in-pipe coagulation-filtration using anthrafilt and sand in a 7 foot deep bed. With the high loadings of 16 to 32 gpm/sq ft surface area, removal of solids was effectively accomplished throughout the entire depth of filter column. Test work showed suspended solids removal up to and exceeding 90 percent and BOD removals in the range of 60 to 80 percent. Substantial reductions, in the order of 30 to 80 percent of phosphates, can also be obtained. A large-scale high-rate filtration unit in New York City is being evaluated for the dual-treatment of dry and wet-weather flows (P-39).

Results from a 5.0 mgd screening and dissolved-air flotation demonstration pilot plant in Milwaukee (20), indicate that greater than 70 percent removals of BOD and suspended solids are possible. By adding chemical coagulants, 85 to 97 percent phosphate reduction can be achieved as an additional benefit. Based on these findings two full-scale prototypes (20 and 40 mgd) have been demonstrated in Racine, WI (P-23).

### Land Disposal

As previously discussed, the use of marshlands for disposal of stormwater has been demonstrated in Minnesota. The feasibility of land disposal of raw CSO has also been investigated (161). Because of the cost of collection and transportation and large land requirements this concept does not appear feasible. Land disposal of CSO sludges, liquid or dewatered, appears feasible and promising for ultimate sludge disposal; however, further investigation in this area is required.

### Biological Treatment

The following biological processes have been demonstrated: contact stabilization (117), high-rate trickling filtration (95), rotating biological contactors (106), and lagoons (108,30). The processes have had positive evaluation, but with the exception of long term storage lagoons, must operate conjunctively with DWF plants to supply biomass, and require some form of flow equalization.

## Disinfection

Because disinfectant and contact demands are great for storm flows, research has centered on high-rate applications by mixing and more rapid oxidants, i.e., chlorine dioxide ($ClO_2$) and ozone ($O_3$); and on-site generation (149,31,34,78,94,105,119). Because of new concerns, a recent grant supplement tied onto a full-scale demonstration in Syracuse, NY (P-2) will allow viral disinfection and carcinogenic chlorine residual compound studies.

## Treatment Process Performance

Treatment process performance in terms of design influx rate (gpm/sq ft) and $BOD_5$ and suspended solids (SS) removal efficiency is provided in Table 12. The high-rate performance of the swirl, microstrainer, filter, and dissolved air flotation is apparent when compared to sedimentation.

Table 12. Wet-Weather Treatment Plant Performance Data

| Device | Control Alternatives | Design Loading Rate ($gpm/ft^2$) | Removal Efficiency (%) | |
|---|---|---|---|---|
| | | | $BOD_5$ | SS |
| Primary | Swirl Concentrator[a,b] | 60 | 25-60 | 50 |
| | Microstrainer[c] | 20 | 40-60 | 70 |
| | High-Rate Filtration[d] | 24 | 60-80 | 90 |
| | Dissolved Air Flotation[d] | 2.5 | 50-60 | 80 |
| | Sedimentation[e] | 0.5 | 25-40 | 55 |
| | Representative Performance | | 40 | 60 |
| Secondary | Contact Stabilization[f] | | 75-88 | 90 |
| | Physical-Chemical[g] | | 85-95 | 95 |
| | Representative Performance | | 85 | 95 |

[a] Field, 1976 (R-16)

[b] Sullivan, 1974 (101)

[c] Maher, 1974 (105)

[d] Lager and Smith, 1974 (102); w/chem. add.; hi-rate filter incl. pre-screens

[e] Performance data based on domestic wastewater treatment

[f] Agnew, et al., 1975 (117)

[g] Estimate based on performance of these units for domestic wastewater (102)

## Treatment: Products

The products associated with the treatment category up to this point are in the form of project final reports and design/user's manuals as referenced.

## SLUDGE/SOLIDS

Due to the documented deleterious effect of CSO on the quality of receiving waters, WWF sludge handling and disposal has been given less emphasis previously in concession to the problems of treating the combined overflow itself. Sludge handling and disposal should be considered an integral part of CSO treatment because it significantly affects the efficiency and cost of the total waste treatment system. Flow characterization studies show that the annual quantity of CSO solids is at least equal to and in most cases greater than solids from DWF. For example, 29% of the sewered population in the U.S. is served by combined sewers. This represents a service area of $3x10^6$ acres. Assuming an average yearly rainfall of 36 in. and 50% of the runoff resulting in an overflow, the yearly volume of CSO in the U.S. would be $1.5X10^{12}$ gal. The corresponding average yearly volume of sludge resulting from treatment of all CSO nationwide is estimated at $41X10^9$ gal or 2.8% of the volume tested. The average solids content of this sludge would be about 1%.

In comparison, an average yearly volume of dry weather sludge of $35X10^9$ gal may be expected from the same service area.

Consequently, if nationwide CSO treatment was instituted there would be an equal or greater problem with CSO sludge as there now is with municipal sludge.

The chronology of the Program's WWF sludge/solids technological advancement is contained in Figure 22. The need for defining the problem was recognized and, in FY 73, a contract was awarded (P-21) to characterize and preliminarily quantify CSO sludge/solids and perform treatability studies. Sludge handling/disposal techniques are also being evaluated and a nationwide assessment of the sludge problem has been conducted (P-24). As part of this assessment, the "impacts" of the following alternatives are being considered: bleed-back of the sludge to the municipal dry weather treatment plant, handling the sludges with parallel facilities at the dry weather plant, handling the sludges at the site of CSO treatment, and land disposal of either untreated or treated sludges.

## Sludge: Products (Table 13)

Two reports are presently available (159,161). The first covers the characterization, treatability, and quantification of CSO sludges and solids and the second is a "rough cut" at assessing the impact of handling and disposal.

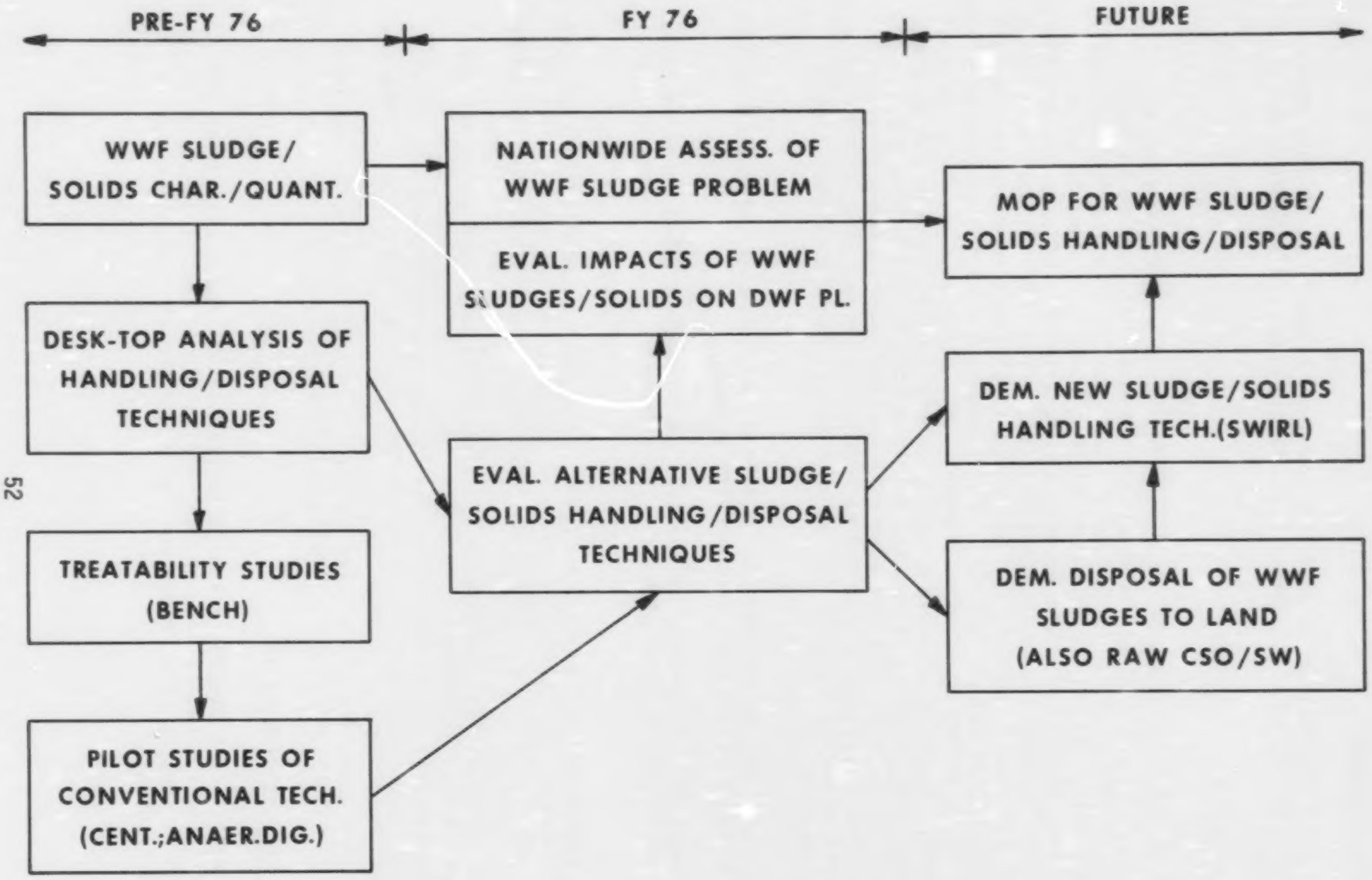

PRE-FY 76
FY 76
FUTURE
WWF SLUDGE/ SOLIDS CHAR./QUANT.
DESK-TOP ANALYSIS OF HANDLING/DISPOSAL TECHNIQUES
TREATABILITY STUDIES (BENCH)
PILOT STUDIES OF CONVENTIONAL TECH. (CENT.;ANAER.DIG.)
NATIONWIDE ASSESS. OF WWF SLUDGE PROBLEM
EVAL. IMPACTS OF WWF SLUDGES/SOLIDS ON DWF PL.
EVAL. ALTERNATIVE SLUDGE/ SOLIDS HANDLING/DISPOSAL TECHNIQUES
MOP FOR WWF SLUDGE/ SOLIDS HANDLING/DISPOSAL
DEM. NEW SLUDGE/SOLIDS HANDLING TECH.(SWIRL)
DEM. DISPOSAL OF WWF SLUDGES TO LAND (ALSO RAW CSO/SW)

Figure 22. Sludge/Solids

Table 13. Sludge/Solids: Products

- Characterization and Quantification of CSO Sludges and Solids. (Draft report available) (159)
- WWF Sludge/Solids Impact Assessment. (Preliminary Report available) (161)
- WWF Sludge/Solids Treatability Studies. (159)

The characterization, quantification, and treatability evaluation of sludges from separate stormwater will be done in the future.

## INTEGRATED SYSTEMS

By far the most promising and common approaches to urban stormwater management involve the integrated use of control and treatment with an area-wide multidisciplinary perspective. When a single method is not likely to produce the best possible answer to a given pollution situation, various treatment and control measures may be combined for maximum flexibility and efficiency.

Integrated systems is divided into (1) Storage/Treatment, (2) Dual Use WWF/DWF Facilities, and (3) Control/Treatment/Reuse (Figure 23).

### Storage/Treatment

Where there is storage, there is treatment by settling, pumpback to the municipal works, and sometimes disinfection; and treatment, which receives detention, provides storage. In any case, the break-even economics of supplying storage must be evaluated when treatment is considered (35). The program has demonstrated all of these storage-treatment concepts on a full-scale basis (15,18,25,26,29,30,40,72,102,108,114,118,134,146,147,154, P-10, P-37).

### Dual Use, WWF/DWF Facilities

The concept of dual use is -- maximum utilization of wet-weather facilities during nonstorm periods and maximum utilization of dry-weather facilities during storm flows for total system effectiveness. The program has demonstrated the dual use of high-rate trickling filters (95), contact stabilization (117), and equalization basins (107,114). On a pilot scale the Program has evaluated advanced physical-chemical treatment (81); and is in the process of demonstrating large-scale, high-rate filtration (P-39).

It should also be mentioned that combined sewers themselves are dual use systems.

### Control/Treatment/Reuse

The sub-category, "Control/Treatment/Reuse" is a "catch-all" for all

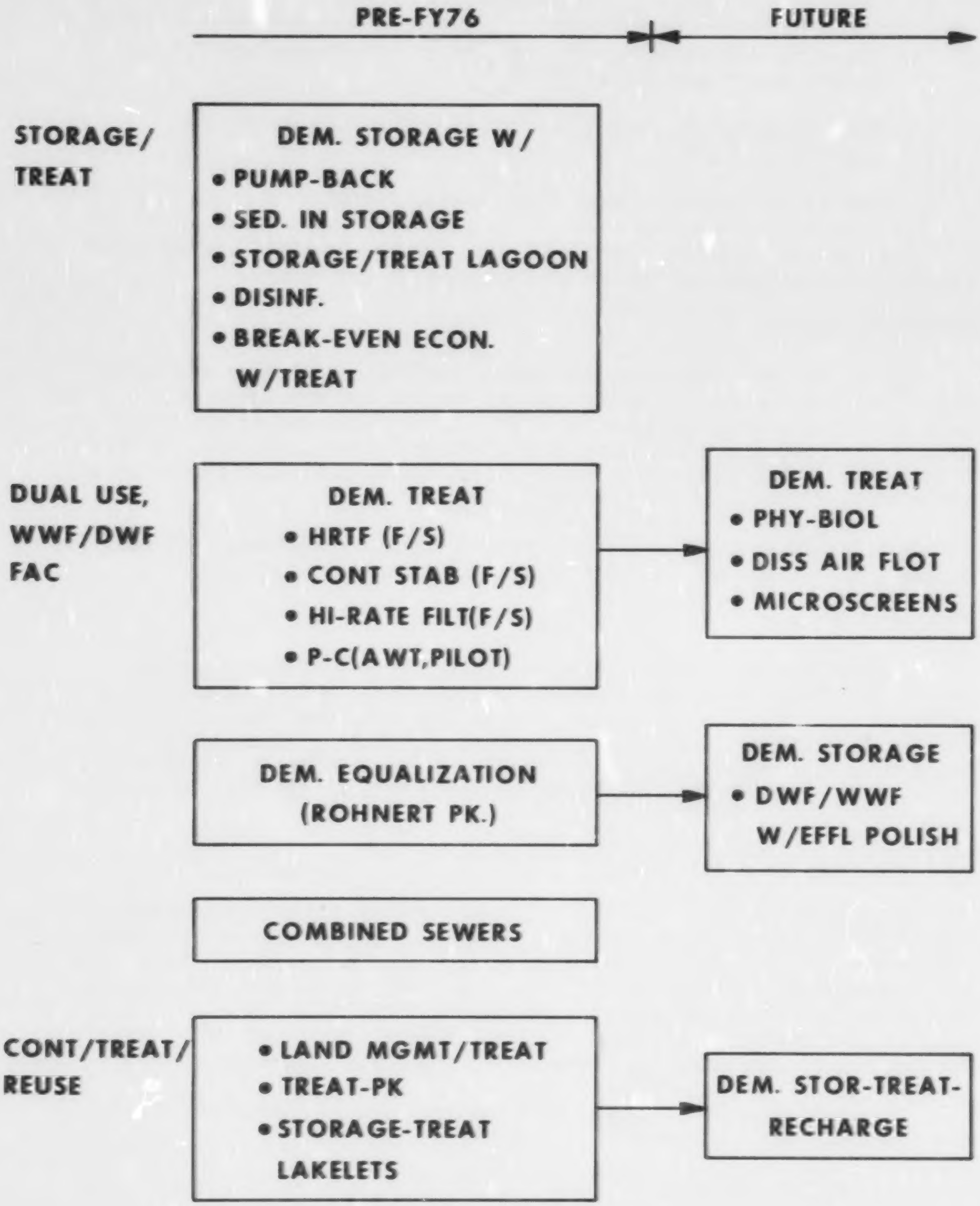

PRE-FY76
FUTURE
STORAGE/ TREAT
DEM. STORAGE W/
• PUMP-BACK
• SED. IN STORAGE
• STORAGE/TREAT LAGOON
• DISINF.
• BREAK-EVEN ECON. W/TREAT
DUAL USE, WWF/DWF FAC
DEM. TREAT
• HRTF (F/S)
• CONT STAB (F/S)
• HI-RATE FILT(F/S)
• P-C(AWT,PILOT)
DEM. TREAT
• PHY-BIOL
• DISS AIR FLOT
• MICROSCREENS
DEM. EQUALIZATION (ROHNERT PK.)
DEM. STORAGE
• DWF/WWF W/EFFL POLISH
COMBINED SEWERS
CONT/TREAT/ REUSE
• LAND MGMT/TREAT
• TREAT-PK
• STORAGE-TREAT LAKELETS
DEM. STOR-TREAT-RECHARGE

Figure 23. Integrated Systems

integrated systems. As the prime consideration, it is reasonable to apply the various non-structural and land management techniques to reduce downstream loads and treatment costs.

Previous projects have evaluated the reuse of stormwater runoff for aesthetic, recreational, and subpotable and potable water supply purposes (62,79). In Mt. Clemens, MI, a series of three "lakelets" has been incorporated into a CSO treatment-park development (114). Treatment and disinfection is being provided so that these lakes are aesthetically pleasing and allow for recreation and reuse for irrigation. Other projects have shown the feasibility of reclaiming stormwater (3,39).

The previously mentioned Houston project (P-16) is focusing on how a "natural drainage system" can be integrated into a reuse scheme for recreation and aesthetics.

### Integrated Systems: Products

The specific outputs from the integrated systems work have been predominantly in the form of demonstrations, documented by final reports. The previously referenced SOTA Assessment Report (102) neatly summarizes the work in this area and ties it into wastewater management systems planning, design, and program implementation. Specific demonstration products are classified into main and complementary units for interrelating storm flow devices and unit processes and interfacing with dry-weather facilities. In the future it is important to evaluate storage used for DWF and WWF along with secondary effluent polishing.

## TECHNICAL ASSISTANCE/TECHNOLOGY TRANSFER

The Technology Transfer area covers the formal dissemination of Program findings in the form of actual project reports, films, journal papers, SOTA reports, and manuals of practice and instruction. To date the Program has published approximately 160 reports, and it is the intent here to concentrate on the "user" type of document.

### SIGNIFICANT DOCUMENTS COMPLETED

Reports generated by the program have received widespread recognition both within this country and abroad. Many have been referenced by EPA Headquarters and used for 201/208 studies. Some of the more significant documents are indicated in Table 14. The first set of reports, item No. 1, set the pace for EPA's Program by identifying stormwater and combined sewer overflow as major sources of water pollution and provided a characterization data base (Refs. see item 1, Table 14.). As previously mentioned, the manuals of practice on infiltration/inflow (27,28,97) and regulators (23,24), Nos. 3 and 4, flagged two prime and basic problems leading to fruitful countermeasure research and a national emphasis on I/I control. Specific research products coming out of the regulator MOP's were the

Table 14. Significant Documents Completed

1. Assessment - Problems of CSO/SW (2,20,34,35,41,47,51,53,54,59,60,63,65,67,73,81,82,83,88,102,112,123,124,127,128,143,149)
2. CSO/SW Seminar Reports (6,40,96,140a)
3. MOP - I/I Prevention and Correction (27,28,97)
4. MOP - Regulation and Management (23,24)
5. Design Manuals - Swirl: Regulator/Degritter/Erosion Control (69,93,99,101)
6. Design Manual - Helical Regulator/Separator (132)
7. Assessments - Sources/Impacts of Urban Runoff Pollution (157,164,127,88,128,73)
8. Assessments - Sampling/Flowrate Measurement (133,130)
9. Assessment - Impact of Deicing (67,86)
10. MOP's - Deicing Chemical Usage/Storage & Handling (100,104)
11. Assessment - SOTA Urban Stormwater Management Technology (102,111,137)
12. Users Manuals - SWMM, Version I and II (44,116)
13. Course Manual - SWMM Application (125)
14. SOTA - Urban Water Management Modeling (136)
15. MOP - Determination of Flowrates/Volumes (140)
16. Assessment/MOP - Stormwater Models (141)
17. MOP - Procedures for Stormwater Characterization/Treatment Studies (145)
18. MOP's - Sediment & Erosion Control (68,70,168,169)
19. User's Manuals - Simplified Urban Runoff Planning Models/Tools (148,153)
20. Assessment - Nationwide Stormwater/Characterization/Impacts/Costs (157)

swirl (69,93,99,101) and helical (132) devices -- resultant design manuals are listed as Nos. 5 and 6. No. 8 cites two instrumentation reports (130,133) for flow analysis which have proven to be highly useful to the engineering community, including Construction Grants. An assessment of the significant impacts of highway deicing chemical use (67,86) and practicable MOP's on control through proper salt storage and use (100, 104) are covered by items 9 and 10. Nos. 11 through 18 relate to Approach and Solution Methodology, the goal of the program. Item 19 refers to two very important user's manuals containing relatively simple urban runoff assessment planning methods (148,153) which can be applied to 201 and 208 studies; and item 20 cites the previously mentioned national assessment of urban runoff control and costs (157).

## SIGNIFICANT DOCUMENTS ANTICIPATED (Table 15)

In the immediate future a construction and O&M cost estimating manual (156) for CSO storage and treatment will be released, along with three other assessments: two on WWF sludge handling, disposal, and impact problems (159,161), and the other on pathogens in stormwater (160).

Ongoing work will also lead to an updated SOTA and a planning document providing guidance and examples for total municipal studies (P-5) and a refined SWMM user's manual (P-53).

Table 15. Significant Documents Anticipated

Estimating Manual - CSO Storage and Treatment Costs (156)
User's Manual - SWMM Version III
Assessments - WWF Sludge Handling/Disposal Problems/Impacts (159/161)
Assessment - Pathogens in Stormwater and Combined Sewer Overflow (160)
SOTA/Planning Guide - Update Storm and Combined Sewer Overflow Management and Treatment/Total Approach Methodology
Design Manual - Swirl: Primary Treatment
MOP - I/I Analysis, Prevention and Control
Instruction Manual - Storm and Combined Sewer Overflow Technology
Post FY 76
MOP - Pollution Control from Construction Activities
MOP - Refined Solution Methodology
MOP - Land Management
Design Manual - Storage Facilities
Consolidated Design Text - Swirl and Helical

## CAPITAL COSTS COMPARISONS FOR STORM AND COMBINED SEWER CONTROL/TREATMENT

Table 16 shows a capital cost comparison for various SCS control and treatment methods.

Sewer separation is very costly with a national average of $20,000/ac (2,102). In-system control storage costs were found to be as low as $0.02 and $0.25/gal for Detroit and Seattle, respectively (R-6d, 111). These figures represented 1/10th the cost for large off-line facilities, and 1/25th the costs for separation in Detroit and Seattle, respectively. Off-line storage varies from $0.03 to $4.75/gal depending on whether earthen or concrete basins are employed (102).

Per acre costs can only be given in wide ranges since they significantly vary with climate, receiving water, terrain, degree of urbanization, sewer network configuration, etc. Per capita and per acre unit costs may be applicable for gross estimating; but it is best to fix unit costs per gallon for storage and per mgd for treatment as design factors for the user engineer confronted with site-specific conditions.

These data are based on a limited number of specific projects thus they represent only a range of placement. In extrapolating these costs into master plan systems for cities, the totals frequently approach $500 to $1,000 per capita.

Physical treatment costs range between $2,000 to $35,000/mgd; whereas physical with chemical treatment varies between $35,000 and $80,000/mgd. Biological treatment ranges between $17,000 and $80,000/mgd depending on whether land is available for lagooning or if contact stabilization or trickling filtration (102) is resorted to. As can be seen from the table, costs for the swirl at $2,000/mgd and $500/acre (P-4) are considerably lower than other forms of treatment installation.

Preliminary figures for incorporating land management techniques show a definite cost-effectiveness benefit.

It must be mentioned that the various alternatives offer different degrees of removal which will have a significant bearing on the selection process.

Table 16. Typical Capital Costs for SCS Control/Treatment (ENR 2000)

| COMPONENT DEVICES | $/GAL | $/MGD | $/ACRE |
|---|---|---|---|
| **SEPARATION** | | | 10,000 (SEATTLE)<br>6,500 (DES MOINES)<br>32,000 (CLEVELAND)<br>20,000-NATIONAL AVE. |
| **STORAGE** | | | |
| • IN-LINE | 0.02 - 0.25<br>(DETROIT) (SEATTLE) | | 400 (SEATTLE)<br>250 (MINNEAPOLIS) |
| • OFF-LINE | | | |
| -EARTHEN | 0.03-0.26 | | |
| -CONCRETE TANKS | 1.00-4.75 | | 7,000 (JAMAICA,NYC) |
| **TREATMENT** | | | |
| • PHYSICAL W&W/O CHEMICALS | | | |
| -FINE SCREENING/MICROSTRAINING | | 5,000/12,000 | 2,000/13,000 |
| -SEDIMENTATION | | 10,000-50,000 | 3,500-6,500 |
| -HI-RATE FILT | | 70,000 | 10,000 |
| -DISS AIR FLOAT | | 40,000 | 6,500 (MILWAUKEE) |
| -SWIRL | | 8,000 (SYRACUSE)<br>2,000 (LANCASTER) | 500(SYRACUSE)<br>500(LANCASTER) |
| •BIOLOGICAL | | | |
| -CON. STAB/TRICK. FILTER | | 80,000 | 1,700 |
| -LAGOONS | | 17,000 | 5,000 |
| •PHYSICAL-CHEMICAL SYSTEMS | | $150{,}000\text{-}2\times10^6$ | |
| •DISINFECTION | | | |
| -CONVENTIONAL | | 1,500 | |
| -HI-RATE(STATIC MIXING) | | 900 | |
| **INTEGRATED SYSTEMS** | | | |
| •STORAGE/TRMT/REUSE | | $1\times10^6$(KINGMAN LAKE) | 10,000(KINGMAN LAKE) |
| -TREATMT-PARK CONCEPT | | 17,000(MT. CLEMENS) | 5,000(MT. CLEMENS) |
| **LAND MANAGEMENT** | | | |
| •STRUCTURAL | | | |
| -DIVERSION BERMS | | | 160 |
| •NON-STRUCTURAL | | | |
| -STREET CLEANING | | | 0.7 |

## SEATTLE: IN-LINE STORAGE IS COST-EFFECTIVE

A case study illustrating cost-effectiveness by Seattle's flow routing approach is worthwhile discussing (98,140a).

### COSTS

The Seattle in-line storage system covering 13,250 acres costs $5.3M or $400 per acre as opposed to tens of thousands of dollars per acre for other alternatives. A specific Seattle study revealed $10,000 per acre for separation. The low cost is attributed to a quasi-structural system which takes advantage of the existing combined sewer network; and control gates installed at strategic points only. The system is highly signal and computer oriented with minimal hardware requirements. In fact, one-half the costs were for computers and related software. Of course, in-line storage is site specific since implementation of the concept requires a relatively large and flat existing combined system.

### POLLUTANT REDUCTION

Overflow and pollutant reduction from 12 major overflow points averaged 55% and 68%, respectively. Also, 90% of the overflow volume was reduced by experimental automatic control.

### EFFECTIVENESS

Effectiveness of the system is proven by a one to two mg/l D.O. increase and a 50% coliform reduction in the receiving water.

## DES MOINES: CONTROL COSTS VS. D.O. VIOLATIONS

Based on a study for the City of Des Moines (157) using a simplified receiving water model, four control alternatives were compared considering cost and true effectiveness in terms of frequency of D.O. standard violations.

As Table 17 depicts, 25% BOD removal of WWF coupled with secondary treatment of DWF results in slightly higher D.O. levels in the receiving water than tertiary treatment and no control of urban runoff. The annual cost of 25% BOD removal for WWF is 10% of the cost for tertiary treatment. However, existing DWF treatment facilities exhibit a comparable effect to these two options at no additional cost. However, significant increase in the minimum D.O. levels of the Des Moines River is obtained by 75% BOD removal of WWF with the annual cost of this level of control being lower than the cost of tertiary treatment. The application to Des Moines demonstrated clearly the overwhelming effect of urban runoff pollution on critical D.O. concentrations. The cost-effectiveness of various treatment alternatives can be determined realistically only by a continuous analysis of the frequency of water quality violations.

In the selection of the "best" control strategy, other factors that may become important are: (1) recovery of receiving waters from shock loads caused by runoff, (2) local and regional water quality goals, and (3) public willingness to pay the costs associated with each level of control.

Table 17. Des Moines: Control Costs vs Violations of DO Standard (4 PPM)

| Options | Total Annual Cost ($/yr) | % of Precipitation Events Violating Standard |
|---|---|---|
| 1. DWF Tertiary Treatment | 6.3M | 40 |
| 2. WWF 25% BOD Removal | 0.6M | 30 |
| 3. WWF 75% BOD Removal | 4.0M | 3 |
| 4. DWF Secondary Trt Only | 0 | 42 |

# CONCLUSION

The pertinent research needs in the areas of solution methodology, nonstructural and structural control and treatment techniques, and integrated systems have been covered in enough detail now to conclude with an item of overlying importance. Mandates of the law are upon us, emphasizing WWF pollution control; monies are being spent at large scale by EPA and others for water pollution cleanup. In order for governments to execute their function in this area properly, it is a must that WWF pollution be considered and R&D be fostered to back this need.

# REFERENCES AND BIBLIOGRAPHY

Bibliography of Urban Runoff Control Program Reports

Ongoing Urban Runoff Pollution Control Projects ("P" Numbers)

Other Urban Runoff Pollution Control Program References ("R" Numbers)

## BIBLIOGRAPHY OF URBAN RUNOFF POLLUTION CONTROL PROGRAM REPORTS

| Ref. No. | Report Number | Title/Author | Source |
|---|---|---|---|
| 1. | 11020---09/67 | Demonstrate the Feasibility of the Use of Ultrasonic Filtration in Treating the Overflows from Combined and/or Storm Sewers: by Accoustica Assoc., Inc., Los Angeles, CA | NTIS ONLY<br>PB 201 745 |
| 2. | 11020---12/67 | Problems of Combined Sewer Facilities and Overflows-1967: by American Public Works Assoc., Chicago, IL | NTIS ONLY<br>PB 214 469 |
| 3. | 11020---05/68 | Feasibility of a Stabilization-Retention Basin in Lake Erie at Cleveland, OH: by Havens and Emerson, Cleveland, OH | NTIS ONLY<br>PB 195 083 |
| 4. | 11020---06/69 | Reduction in Infiltration by Zone Pumping: by Hoffman and Fiske, Lewiston, ID | NTIS ONLY<br>PB 187 868 |
| 5. | 11020---10/69 | Crazed Resin Filtration of Combined Sewer Overflows: by Hercules, Inc., Wilmington, DE | NTIS ONLY<br>PB 187 867 |
| 6. | 11020---03/70 | *Combined Sewer Overflow Seminar Papers: by Storm and Combined Sewer Pollution Control Branch, Division of Applied Science and Technology, FWQA, Washington, DC | NTIS<br>PB 199 361 |
| 7. | 11020---02/71 | *Deep Tunnels in Hard Rock: by College of Applied Science and Engineering and University Extension, University of Wisconsin, Milwaukee, WI | NTIS<br>PB 210 854 |
| 8. | 11020DES06/69 | Selected Urban Water Runoff Abstracts: by The Franklin Institute, Philadelphia, PA | NTIS ONLY<br>PB 185 314 |

*Copies may be obtained from EPA Storm & Combined Sewer Section, Edison, NJ 08817

Note: Number in left margin corresponds to reference numbers cited in report text.

| Ref. No. | Report Number | Title/Author | Source |
|---|---|---|---|
| 9. | 11020DGZ10/69 | Design of a Combined Sewer Fluidic Regulator: by Bowles Engineering Corp., Silver Spring, MD | NTIS ONLY<br>PB 188 914 |
| 10. | 11020DHO06/72 | *Ground Water Infiltration and Internal Sealings of Sanitary Sewers, Montgomery County, OH: by G.E. Cronk | NTIS<br>PB 212 267 |
| 11. | 11020DIG08/69 | Polymers for Sewer Flow Control: by The Western Co., Richardson, TX | NTIS ONLY<br>PB 185 951 |
| 12. | 11020DIH06/69 | Improved Sealants for Infiltration Control: by The Western Company, Richardson, TX | NTIS ONLY<br>PB 185 950 |
| 13. | 11020DNO08/67 | Feasibility of a Periodic Flushing System for Combined Sewer Cleansing: by FMC Corp., Santa Clara, CA | NTIS ONLY<br>PB 195 223 |
| 14. | 11020DNO03/72 | *A Flushing System for Combined Sewer Cleansing: by Central Engineering Laboratories, FMC Corp., Santa Clara, CA | NTIS<br>PB 210 858 |
| 15. | 11020DWF12/69 | Control of Pollution by Underwater Storage: by Underwater Storage, Inc., Silver, Schwartz, Ltd., Joint Venture, Washington, DC | NTIS ONLY<br>PB 191 217 |
| 16. | 11020EKO10/69 | Combined Sewer Separation Using Pressure Sewers: by American Society of Civil Engineers, Cambridge, MA | NTIS ONLY<br>PB 188 511 |
| 17. | 11020EXV07/69 | Strainer/Filter Treatment of Combined Sewer Overflows: by Fram Corporation, East Providence, RI | NTIS ONLY<br>PB 185 949 |
| 18. | 11020FAL03/71 | *Evaluation of Storm Standby Tanks, Columbus, OH: by Dodson, Kinney & Lindblom, Columbus, OH | NTIS<br>PB 202 236 |
| 19. | 11020FAQ03/71 | *Dispatching Systems for Control of Combined Sewer Losses: by Metro. Sewer Board, St. Paul, MN | NTIS<br>PB 203 678 |

*Copies may be obtained from EPA Storm & Combined Sewer Section, Edison, NJ 08817

| Ref. No. | Report Number | Title/Author | Source |
|---|---|---|---|
| 20. | 11020FDC01/72 | Screening/Flotation Treatment of Combined Sewer Overflows: by The Ecology Division, Rex Chainbelt, Inc., Milwaukee, WI | GPO ONLY |
| 21. | 11020FKI01/70 | Dissolved-Air Flotation Treatment of Combined Sewer Overflows: by Rhodes Corp., Oklahoma City, OK | NTIS ONLY<br>PB 189 775 |
| 22. | 11022DEI05/72 | *Sewer Bedding and Infiltration Gulf Coast Area: by J.K.Mayer, F.W.Mac Donald, and S.E.Steimle; Tulane Univ., New Orleans, LA | NTIS<br>PB 211 282 |
| 23. | 11022DMU07/70 | *Combined Sewer Regulator Overflow Facilities: by American Public Works Assoc., Chicago, IL | GPO ONLY |
| 24. | 11022DMU08/70 | *Combined Sewer Regulation and Management A Manual of Practice: by American Public Works Assoc., Chicago, IL | NTIS<br>PB 195 676 |
| 25. | 11022DPP10/70 | *Combined Sewer Temporary Underwater Storage Facility: by Melpar, Falls Church, VA | NTIS<br>PB 197 669 |
| 26. | 11022ECV09/71 | Underwater Storage of Combined Sewer Overflows: by Karl R. Rohrer Assoc., Inc., Akron, OH | NTIS ONLY<br>PB 208 346 |
| 27. | 11022EFF12/70 | Control of Infiltration and Inflow into Sewer Systems: by American Public Works Assoc., Chicago, IL | NTIS ONLY<br>PB 200 827 |
| 28. | 11022EFF01/71 | *Prevention and Correction of Excessive Infiltration and Inflow into Sewer Systems-A Manual of Practice: by American Public Works Assoc., Chicago, IL | NTIS<br>PB 203 208 |
| 29. | 11022ELK12/71 | Maximizing Storage in Combined Sewer Systems: by Municipality of Metropolitan Seattle, WA | NTIS ONLY<br>PB 209 861 |

*Copies may be obtained from EPA Storm & Combined Sewer Section, Edison, NJ 08817

| Ref. No. | Report Number | Title/Author | Source |
|---|---|---|---|
| 30. | 11023---08/70 | *Retention Basin Control of Combined Sewer Overflows: by Springfield Sanitary District, Springfield, IL | NTIS<br>PB 200 828 |
| 31. | 11023DAA03/72 | *Hypochlorite Generator for Treatment of Combined Sewer Overflows: by Ionics, Inc., Watertown, MA | NTIS<br>PB 211 243 |
| 32. | 11023DPI08/69 | Rapid-Flow Filter for Sewer Overflows: by Rand Development Corp., Cleveland, OH | NTIS ONLY<br>PB 194 032 |
| 33. | 11023DZF06/70 | *Ultrasonic Filtration of Combined Sewer Overflows: by American Process Equipment Corp., Hawthorne, CA | NTIS<br>PB 212 421 |
| 34. | 11023EVO06/70 | *Microstraining and Disinfection of Combined Sewer Overflows: by Cochrane Div., Crane Co., King of Prussia, PA | NTIS<br>PB 195 674 |
| 35. | 11023EYI04/72 | *High Rate Filtration of Combined Sewer Overflows: by Ross Nebolsine, P.J.Harvey, and Chi-Yuan Fan, Hydrotechnic Corp., New York, NY | NTIS<br>PB 211 144 |
| 36. | 11023FDB09/70 | *Chemical Treatment of Combined Sewer Overflows: by Dow Chemical Company, Midland, MI | NTIS<br>PB 199 070 |
| 37. | 11023FDD03/70 | Rotary Vibratory Fine Screening of Combined Sewer Overflows: by Cornell Howland, Hayes and Merryfield, Corvallis, OR | NTIS ONLY<br>PB 195 168 |
| 38. | 11023FDD07/71 | *Demonstration of Rotary Screening for Combined Sewer Overflows: by City of Portland, Dept. of Public Works, Portland, OR | NTIS<br>PB 206 814 |
| 39. | 11023FIX08/70 | *Conceptual Engineering Report-Kingman Lake Project: by Roy F. Weston, West Chester, PA | NTIS<br>PB 197 598 |

*Copies may be obtained from EPA Storm & Combined Sewer Section, Edison, NJ 08817

| Ref. No. | Report Number | Title/Author | Source |
|---|---|---|---|
| 40. | 11024---06/70 | *Combined Sewer Overflow Abatement Technology: by Storm and Combined Sewer Pollution Control Branch, Division of Applied Science and Technology, FWQA, Washington, DC | NTIS<br>PB 193 939 |
| 41. | 11024DMS05/70 | *Engineering Investigation of Sewer Overflow Problems: by Hayes, Seay, Mattern and Mattern, Roanoke, VA | NTIS<br>PB 195 201 |
| 42. | 11024DOC07/71 | *Storm Water Management Model, Vol. I, Final Report: by Metcalf & Eddy Engineers, Palo Alto, CA | NTIS<br>PB 203 289 |
| 43. | 11024DOC08/71 | Storm Water Management Model, Vol. II, Verification and Testing: by Metcalf & Eddy Engineers, Palo Alto, CA | NTIS ONLY<br>PB 203 290 |
| 44. | 11024DOC09/71 | Storm Water Management Model, Vol. III, User's Manual: by Metcalf & Eddy Engineers, Palo Alto, CA | NTIS ONLY<br>PB 203 291 |
| 45. | 11024DOC10/71 | Storm Water Management Model, Vol. IV Program Listing: by Metcalf & Eddy Engineers, Palo Alto, CA | NTIS ONLY<br>PB 203 292 |
| 46. | 11024DOK02/70 | *Proposed Combined Sewer Control by Electrode Potential: by Merrimack College, Andover, MA | NTIS<br>PB 195 169 |
| 47. | 11024DQU10/70 | *Urban Runoff Characteristics: by University of Cincinnati, Cincinnati, OH | NTIS<br>PB 202 865 |
| 48. | 11024EJC07/70 | Selected Urban Storm Water Runoff Abstracts, July 1968-June 1970: by The Franklin Institute Research Lab., Philadelphia, PA | NTIS ONLY<br>PB 198 228 |
| 49. | 11024EJC10/70 | *Selected Urban Storm Water Runoff Abstracts, First Quarterly Issue: by The Franklin Institute Research Lab., Philadelphia, PA | NTIS<br>PB 198 229 |
| 50. | 11024EJC01/71 | *Selected Urban Storm Water Runoff Abstracts, Second Quarterly Issue: by The Franklin Institute Research Lab., Philadelphia, PA | NTIS<br>PB 198 312 |

*Copies may be obtained from EPA Storm & Combined Sewer Section, Edison, NJ 08817

| Ref. No. | Report Number | Title/Author | Source |
|---|---|---|---|
| 51. | 11024ELB01/71 | *Storm and Combined Sewer Pollution Sources and Abatement, Atlanta, GA: by Black, Crow and Eidsness, Inc., Atlanta, GA | NTIS<br>PB 201 725 |
| 52. | 11024EQE06/71 | *Impregnation of Concrete Pipe: by Southwest Research Institute, San Antonio, TX | GPO |
| 53. | 11024EQG03/71 | Storm Water Problems and Control in Sanitary Sewers, Oakland & Berkeley, CA: by Metcalf & Eddy Engineers, Palo Alto, CA | NTIS ONLY<br>PB 208 815 |
| 54. | 11024EXF08/70 | *Combined Sewer Overflow Abatement Alternatives, Washington, DC: by Roy F. Weston, Inc., West Chester, PA | NTIS<br>PB 203 680 |
| 55. | 11024FJE04/71 | *Selected Urban Storm Water Runoff Abstracts, Third Quarterly Issue: by Franklin Institute Research Lab., Philadelphia, PA | GPO |
| 56. | 11024FJE07/71 | *Selected Urban Stormwater Runoff Abstracts July 1970 -June 1971: by The Franklin Institute Research Lab., Philadelphia, PA | GPO |
| 57. | DELETED | DELETED | |
| 58. | 11024FKJ10/70 | *In-Sewer Fixed Screening of Combined Sewer Overflows: by Envirogenics Co., Div. of Aerojet General Corp., El Monte, CA | NTIS<br>PB 213 118 |
| 59. | 11024FKM12/71 | Urban Storm Runoff and Combined Sewer Overflow Pollution, Sacremento, CA: by Envirogenics Co., Div. of Aerojet General Corp., El Monte, CA | NTIS ONLY<br>PB 208 989 |
| 60. | 11024FKN11/69 | *Stream Pollution and Abatement from Combined Sewer Overflows, Bucyrus, OH: by Burgess and Niple, Ltd., Columbus, OH | NTIS<br>PB 195 162 |

*Copies may be obtained from EPA Storm and Combined Sewer Section, Edison, NJ 08817

| Ref. No. | Report Number | Title/Author | Source |
|---|---|---|---|
| 61. | 11024FLY06/71 | *Heat Shrinkable Tubing as Sewer Pipe Joints: by The Western Co. of North America, Richardson, TX | NTIS<br>PB 208 816 |
| 62. | 11030DNK08/68 | The Beneficial Use of Stormwater: by Hittman Associates, Inc., Baltimore, MD | NTIS ONLY<br>PB 195 160 |
| 63. | 11030DNS01/69 | Water Pollution Aspects of Urban Runoff: by American Public Works Assoc., Chicago, IL | NTIS ONLY<br>PB 215 532 |
| 64. | 11034DUY03/72 | *Investigation of Porous Pavements for Urban Runoff Control: by E. Thelen, W.C.Grover, A.J.Hoiberg, and T.I.Haigh, The Franklin Institute Research Lab., Philadelphia, PA | NTIS<br>PB 227 516 |
| 65. | 11034FKL07/70 | Stormwater Pollution from Urban Land Activity: by AVCO Economic Systems Corp., Washington, DC | NTIS ONLY<br>PB 195 281 |
| 66. | 11034FLU06/71 | *Hydraulics of Long Vertical Conduits and Associated Cavitation: by University of Minnesota, Minneapolis, MN | GPO |
| 67. | 11040GKK06/71 | *Environmental Impact of Highway Deicing: by Edison Water Quality Laboratory, EPA, Edison, NJ | NTIS<br>PB 203 493 |
| 68. | 15030DTL05/70 | Urban Soil Erosion and Sediment Control: by National Association of Counties Research Foundation, Washington, DC | NTIS ONLY<br>PB 196 111 |
| 69. | EPA-R2-72-008 | *The Swirl Concentrator as a Combined Sewer Overflow Regulator Facility: by American Public Works Assoc., Chicago, IL | GPO $2.25<br>EP 1.23/2:72-008<br>NTIS<br>PB 214 687 |
| 70. | EPA-R2-72-015 | Guidelines for Erosion and Sediment Control Planning and Implementation: by the Dept. of Water Resources, State of MD, and Hittman Assoc., Inc., Columbia, MD | NTIS ONLY<br>PB 213 119 |

*Copies may be obtained from the EPA Storm and Combined Sewer Section, Edison, NJ 08817

| Ref. No. | Report Number | Title/Author | Source |
|---|---|---|---|
| 71. | EPA-R2-72-068 | *Storm Sewer Design-An Evaluation of the RRL Method: by J.B.Stall and M.L.Tierstriep, Illinois State Water Survey, University of Illinois Urbana, IL | GPO<br>EP 1.23/2:72-068<br>NTIS<br>PB 214 134 |
| 72. | EPA-R2-72-070 | *Storage and Treatment of Combined Sewer Overflows: by the City of Chippewa Falls, WI | GPO<br>EP 1.23/3:72-070<br>NTIS<br>PB 214 106 |
| 73. | EPA-R2-72-081 | *Water Pollution Aspects of Street Surface Contaminants: by J.D.Sartor and G.B.Boyd, URS Research Co., San Mateo, CA | GPO<br>EP 1.23/2:72-081<br>NTIS<br>PB 214 408 |
| 74. | EPA-R2-72-082 | *Feasibility Study of Electromagnetic Subsurface Profiling: by R.M. Morey and W.S. Harrington, Jr., Geophysical Survey Systems, Inc., North Billerica MD | GPO<br>EP 1.23/2:72-082<br>NTIS<br>PB 213 892 |
| 75. | EPA-R2-72-091 | *A Pressure Sewer System Demonstration: by I.G.Carcich, et al, New York State Department of Environmental Conservation, Albany, NY | GPO<br>EP 1.23/2:72-091<br>NTIS<br>PB 214 409 |
| 76. | EPA-R2-72-125 | *A Search: New Technology for Pavement Snow and Ice Control: by D.M. Murray and M.R. Eigerman, ABT Associates, Inc., Cambridge, MD | GPO<br>EP 1.23/2:72-125<br>NTIS<br>PB 221 250 |
| 77. | EPA-R2-72-127 | *Selected Urban Stormwater Runoff Abstracts, July 1971-June 1972: by D.A. Sandoski, The Franklin Institute Research Lab., Philadelphia, PA | GPO<br>EP 1.23/2:72-127<br>NTIS<br>PB 214 411 |
| 78. | EPA-R2-73-124 | Microstraining and Disinfection of Combined Sewer Overflows-Phase II: by G.E. Glover, G.R. Herbert, Crane Company, King of Prussia, PA | GPO<br>EP 1.23/2:73-124<br>NTIS<br>PB 219 879 |
| 79. | EPA-R2-73-139 | *The Beneficial Use of Stormwater: by C.W. Mallory, Hittman Associates, Columbia, MD | GPO<br>EP 1.23/2:73-139<br>NTIS<br>PB 217 506 |

*Copies may be obtained from EPA Storm and Combined Sewer Section, Edison, NJ 08817

| Ref. No. | Report Number | Title/Author | Source |
|---|---|---|---|
| 80. | EPA-R2-73-145 | *A Thermal Wave Flowmeter for Measuring Combined Sewer Flows: by P. Eshleman and R. Blase, Hydrospace Challenger, Inc., Rockville, MD | GPO<br>EP 1.23/2:73-145<br>NTIS<br>PB 227 370 |
| 81. | EPA-R2-73-149 | Physical-Chemical Treatment of Combined and Municipal Sewage: by A.J. Shuckrow, et al., Pacific NW Lab., Battelle Memorial Institute, Richland, WA | GPO<br>EP 1.23/2:73-149<br>NTIS<br>PB 219 668 |
| 82. | EPA-R2-73-152 | *Combined Sewer Overflow Study for the Hudson River Conference: by A.I. Mytelka, et al., Interstate Sanitation Commission, New York, NY (jointly sponsored by Office of Enforcement & General Council and Office of Research & Monitoring, EPA) | GPO<br>EP 1.23/2:73-152<br>NTIS<br>PB 227 341 |
| 83. | EPA-R2-73-170 | *Combined Sewer Overflow Abatement Plan, Des Moines, IA: by P.L.Davis, et al., Hennington, Durham, and Richardson, Inc., Omaha, NE | GPO<br>EP 1.23/2:R2-73-170 |
| 84. | EPA-R2-73-238 | *Flow Augmenting Effects of Additives on Open Channel Flows: by C. Derick and K. Logie, Columbia Research Inc., Gaithersburg, MD | GPO<br>EP 1.23/2:73-238<br>NTIS<br>PB 222 911 |
| 85. | EPA-R2-73-242 | *Temporary Detention of Storm and Combined Sewage in Natural Underground Formations: by City of St. Paul, St. Paul, MN | GPO<br>EP 1.23/2:73-242 |
| 86. | EPA-R2-73-257 | Water Pollution and Associated Effects from Street Salting: by R.Field, H.E.Masters, A.N.Tafuri, Edison Water Quality Research Lab., EPA, Edison, NJ and E.J.Struzeski, EPA, Denver, CO | In-House Report<br>NTIS<br>PB 222 795 |
| 87. | EPA-R2-73-261 | *An Assessment of Automatic Sewer Flow Samplers: by P.E.Shelley and G.W.Kirkpatrick, Hydrospace Challenger Inc., Rockville, MD | GPO<br>EP 1.23/2:R2-73-261<br>NTIS<br>PB 223 355 |

*Copies may be obtained from EPA Storm & Combined Sewer Section, Edison, NJ 08817

| Ref. No. | Report Number | Title/Author | Source |
|---|---|---|---|
| 88. | EPA-R2-73-283 | *Toxic Materials Analysis of Street Surface Contaminants: by R.E.Pitt and G.Amy, URS Research Co., San Mateo, CA | GPO<br>EP 1.23/2:R2-73-283<br>NTIS<br>PB 224 677 |
| 88a | EPA-600/2-73-002 | A Portable Device for Measuring Wastewater Flow in Sewers: by Michael A. Nawrocki, Hittman Associates, Inc., Columbia, MD | GPO<br>EP 1.23/2:600/2-73-002<br>NTIS<br>PB 235 634 |
| 89 | EPA-660/2-73-035 | Joint Construction Sediment Control Project: by B.C.Becker, et al., Water Resources Administration, State of Maryland | GPO<br>EP 1.23/2:660/2-73-035<br>NTIS<br>PB 235 634 |
| 90. | EPA-660/2-74-071 | Programmed Demonstration for Erosion and Sediment Control Specialist: by T.R.Mills, et al., Water Resources Administration, State of Maryland | GPO<br>EP 1.23/2:660/2-74-071 |
| 91. | EPA-660/2-74-072 | Demonstration of the Separation and Disposal of Concentrated Sediments: by M.A. Nawrocki, Hittman Associates, Columbia, MD | GPO<br>EP 1.23/2:660/2-74-072 |
| 92. | EPA-660/2-74-073 | An Executive Summary of Three EPA Demonstration Programs in Erosion and Sediment Control: by B.C.Becker et al., Hittman Associates, Columbia, MD | GPO<br>EP 1.23/2:660/2-74-073 |
| 93. | EPA-670/2-73-059 | *The Dual-Functioning Swirl Combined Sewer Overflow Regulator/Concentrator: by R.Field, USEPA, Edison, NJ | GPO<br>EP 1.23/2:670/2-73-059<br>NTIS<br>PB 227 182/3 |

*Copies may be obtained from EPA Storm and Combined Sewer Section, Edison, NJ 08817

| Ref. No. | Report Number | Title/Author | Source |
|---|---|---|---|
| 94. | EPA-670/2-73-067 | *Hypochlorination of Polluted Stormwater Pumpage at New Orleans: by U.R. Pontius, E.H.Pavis, Byrne Engineering Corp., New Orleans, LA | GPO<br>EP 1.23/2:670/2-73-067<br>NTIS<br>PB 228 581 |
| 95. | EPA-670/2-73-071 | *Utilization of Trickling Filters for Dual-Treatment of Dry and Wet-Weather Flows: by P.Homack, et al., E.T. Killam Assoc., Inc., Millburn, NJ | GPO<br>EP 1.23/2:670/2-73-071<br>NTIS<br>PB 231 251 |
| 96. | EPA-670/2-73-077 | *Combined Sewer Overflow Seminar Papers: by Storm and Combined Sewer Technology Branch, USEPA, Edison, NJ | GPO<br>EP 1.23/2:670/2-73-077<br>NTIS<br>PB 231 836 |
| 97. | EPA-670/9-74-004 | *Excerpts from "Control of Infiltration and Inflow into Sewer Systems," and "Prevention and Correction of Excessive Infiltration and Inflow into Sewer Systems Manual of Practice, January 1971." Complete reports can be purchased from NTIS, See PB numbers listed on third page of this Bibliography. | NTIS Pending |
| 98. | EPA-670/2-74-022 | *Computer Management of a Combined Sewer System: by C.P.Leiser, Municipality of Metropolitan Seattle, Seattle, WA | GPO<br>EP 1.23/2:670/2-74-022<br>NTIS<br>PB 235 717 |
| 99. | EPA-670/2-74-026 | *The Swirl Concentrator as a Grit Separator Device: by R.H.Sullivan, et al., American Public Works Assoc., Chicago, IL | NTIS<br>PB 233 964 |
| 100. | EPA-670/2-74-033 | *Manual for Deicing Chemical Storage and Handling: by D.L.Richardson, et al., Arthur D. Little, Inc., Cambridge, MD | NTIS<br>PB 236 152 |
| 101. | EPA-670/2-74-039 | *Relationship between Diameter and Height for Design of a Swirl Concentrator as a Combined Sewer Overflow Regulator: by R.H.Sullivan, et al., American Public Works Assoc., Chicago, IL | NTIS<br>PB 234 646 |

*Copies may be obtained from EPA Storm and Combined Sewer Section, Edison, NJ 08817

| Ref. No. | Report Number | Title/Author | Source |
|---|---|---|---|
| 102. | EPA-670/2-74-040 | *Urban Stormwater Management and Technology An Assessment: by J.A.Lager and W.G.Smith, Metcalf & Eddy, Inc., Palo Alto, CA | NTIS<br>PB 240 687 |
| 103. | EPA-660/2-74-043 | Prediction of Subsoil Erodibility Using Chemical, Mineralogical and Physical Parameters: by C.B.Roth, D.W.Nelson, M.J.M.Romkens, Cincinnati, OH | GPO<br>EP 1.23/2:660/2-74-043<br>NTIS<br>PB 231 846 |
| 104. | EPA-670/2-74-045 | *Manual for Deicing Chemicals: Application Practices: D.L.Richardson, Arthur D. Little, Inc., Cambridge, MD | NTIS<br>PB 239 694 |
| 105. | EPA-670/2-74-049 | *Microstraining and Disinfection of Combined Sewer Overflows-Phase III: by M.B.Maher, Crane Co., King of Prussia, PA | GPO<br>EP 1.23/2:670/2-74-049<br>NTIS<br>PB 235 771 |
| 106. | EPA-670/2-74-050 | Combined Sewer Overflow Treatment by the Rotating Biological Contactor Process: by F.L.Welsh, D.J.Stucky, Autotrol Corp., Milwaukee, WI | NTIS ONLY<br>PB 231 892 |
| 107. | EPA-670/2-74-075 | *Surge Facility for Wet- and Dry-Weather Flow Control: by H.L.Welborn City of Rohnert Park, CA | GPO<br>EP 1.23/2:670/2-74-075<br>NTIS<br>PB 238 905 |
| 108. | EPA-670/2-74-079 | An Evaluation of Three Combined Sewer Overflow Treatment Alternatives: by J.W.Parks, et al., City of Shelbyville, IL | NTIS ONLY<br>PB 239 115 |
| 109. | EPA-670/2-74-086 | Chemical Impact of Snow Dumping Practices: by J.P.O'Brien, et al., Arthur D. Little, Inc., Cambridge, MD | NTIS ONLY<br>PB 238 764 |
| 110. | EPA-670/2-74-087 | Assessment and Development Plans for Monitoring of Organics in Storm Flows: by A.Molvar, A.Tulmello, Raytheon Co., Portsmouth, RI | NTIS ONLY<br>PB 238 810 |

*Copies may be obtained from EPA Storm and Combined Sewer Section, Edison, NJ 08817

| Ref. No. | Report Number | Title/Author | Source |
|---|---|---|---|
| 111. | EPA-670/2-74-090 | *Countermeasures for Pollution from Overflows: by R.Field, USEPA, and J.A.Lager, Metcalf & Eddy, Inc., Palo Alto, CA | NTIS<br>PB 240 498 |
| 112. | EPA-670/2-74-096 | *Characterization and Treatment of Urban Land Runoff: by Newton V. Colston, Jr., North Carolina State University, Raleigh, NC | NTIS<br>PB 240 978 |
| 113. | EPA-670/2-75-002 | *Suspended Solids Monitor: by John W. Liskowitz, et al., American Standard Inc., New Brunswick, NJ | NTIS<br>PB 241 581 |
| 114. | EPA-670/2-75-010 | *Multi-Purpose Combined Sewer Overflow Treatment Facility, Mt. Clemens, MI: by V.U.Mahida, F.J.DeDecker, Spalding DeDecker & Assoc., Madison Heights, MI | NTIS<br>PB 242 914 |
| 115. | EPA-670/2-75-011 | *Physical and Settling Characteristics of Particulates in Storm and Sanitary Wastewater: by R.J.Dalrymple, et al, Beak Consultants for American Public Works Assoc., Chicago, IL | NTIS<br>PB 242 001 |
| 116. | EPA-670/2-75-017 | *Stormwater Management Model User's Manual-Version II: W.C.Huber, et al., University of Florida, Gainesville, FL | NO NTIS |
| 117. | EPA-670/2-75-019 | *Biological Treatment of Combined Sewer Overflow at Kenosha, WI: by R.W.Agnew, et al., Envirex, Milwaukee, WI | NTIS<br>PB 242 126 |
| 118. | EPA-670/2-75-020 | *Sewage System Monitoring and Remote Control: by T.R.Watt, et al., Detroit Metro Water Department, Detroit MI | NTIS<br>PB 242 107 |
| 119. | EPA-670/2-75-021 | *Bench-Scale High-Rate Disinfection of Combined Sewer Overflows: by P.E. Moffa, et al., O'Brien & Gere Engrs., Syracuse, NY | NTIS<br>PB 242 296 |

*Copies may be obtained from EPA Storm and Combined Sewer Section, Edison, NJ 08817

| Ref. No. | Report Number | Title/Author | Source |
|---|---|---|---|
| 120. | EPA-670/2-75-022 | *Urban Stormwater Management Modeling and Decision-Making: by J.P.Heaney and W.C.Huber, University of Florida, Gainesville, FL | NTIS<br>PB 242 290 |
| 121. | EPA-670/2-75-035 | Stream Pollution Abatement by Supplemental Pumping: by C.W.Reh and W.E. Saddler, City of Richmond, VA | NTIS ONLY<br>PB 239 566 |
| 122. | EPA-670/2-75-041 | *Storm Water Management Model: Dissemination and User Assistance: J.A.Hagerman and F.R.S.Dressler, University City Science Center (UCSC), Philadelphia, PA | NTIS<br>PB 2242 544 |
| 123. | EPA-670/2-75-046 | *Rainfall-Runoff Relations on Urban and Rural Areas: by E.F.Brater and J.D.Sherrill, University of Michigan, Ann Arbor, MI | NTIS<br>PB 242 830 |
| 124. | EPA-670/2-75-054 | Characterization and Treatment of Combined Sewer Overflows: by Engineering Science Inc. for City and County of San Francisco, CA | NTIS ONLY<br>PB 241 299 |
| 125. | EPA-670/2-75-065 | *Short Course Proceedings, Application of Stormwater Management Models: F.DiGiano, et al., University of Massachusetts, Amherst, MA | NTIS<br>PB 247 163 |
| 126. | EPA-670/2-75-067 | *Automatic Organic Monitoring System for Storm and Combined Sewers: by A.Tulumello, Raytheon Co., Portsmouth, RI | NTIS<br>PB 244 142 |
| 127. | EPA-440/9-75-004 | *Water Quality Management Planning for Urban Runoff: by G.Amy, et al., Woodward-Clyde, San Francisco, CA | NTIS<br>PB 241 689 |
| 128. | EPA-600/2-75-004 | *Contributions of Urban Roadway Usage to Water Pollution: by D.G.Shaheen, Biospherics Inc., Rockville, MD | NTIS<br>PB 245 854 |

*Copies may be obtained from EPA Storm and Combined Sewer Section, Edison, NJ 08817

| Ref. No. | Report Number | Title/Author | Source |
|---|---|---|---|
| 129. | EPA-600/2-75-007 | Impact of Hydrologic Modifications on Water Quality: by J.Bhutani, et al., Mitre Inc., McLean, VA | NTIS<br>PB 248 523 |
| 130. | EPA-600/2-75-027 | *Sewer Flow Measurement-A State-of-the-Art Assessment: by P.E.Shelley and G.A.Kirkpatrick, EG&G Washington Analytical Services Center, Inc., Rockville, MD | NTIS<br>PB 250 371 |
| 131. | EPA-600/2-75-033 | *A Treatment of Combined Sewer Overflows by Dissolved Air Flotations: by T.A.Bursztynsky, et al., Engineering Science Inc., Berkeley, CA | NTIS<br>PB 248 186 |
| 132. | EPA-600/2-75-062 | *The Helical Bend Combined Sewer Overflow Regulator: by R.H.Sullivan, et al., American Public Works Assoc., Chicago, IL | NTIS<br>PB 250 619 |
| 133. | EPA-600/2-75-065 | *An Assessment of Automatic Sewer Flow Samplers-1975: by P.E.Shelley, EG&G Washington Analytical Services Center, Inc., Rockville, MD | NTIS<br>PB 250 987 |
| 134. | EPA-600/2-75-071 | *Detention Tank for Combined Sewer Overflow: by Consoer, Townsend and Associates, Milwaukee, WI | NTIS<br>PB 250 427 |
| 135. | EPA-600/2-76-006 | *Design and Testing of a Prototype Automatic Sewer Sampling System: by P.Shelley, EG&G Washington Analytical Service Center Inc., Rockville, MD | NTIS<br>PB 252 613 |
| 136. | EPA-600/2-76-058 | Future Direction of Urban Water Models: by M.Sonnen, Water Resources Engineers (WRE), Walnut Creek, CA | NTIS ONLY<br>PB 249 049 |
| 137. | EPA-600/2-76-095 | *Urban Runoff Pollution Control Program Overview: FY 76: R.Field, A.N.Tafuri, H.E.Masters, USEPA, Edison, NJ | NTIS<br>PB 252 223<br>In-house Report |

*Copies may be obtained from EPA Storm and Combined Sewer Section, Edison, NJ 08817

| Ref. No. | Report Number | Title/Author | Source |
|---|---|---|---|
| 138. | EPA-600/2-76-105 | *An Economic Analysis of the Environmental Impact of Highway Deicing: by D.M.Murray and U.F.W.Ernst, Abt Associates, Inc., Cambridge, MA | NTIS<br>PB 253 268 |
| 139. | EPA-600/2-76-115 | *A Passive Flow Measurement System for Storm and Combined Sewer: by K.Foreman, Grumman Ecosystems Corp., Bethpage, NY | NTIS<br>PB 253 383 |
| 140. | EPA-600/2-76-116 | *Urban Stormwater Runoff Determination of Volumes and Flowrates: by B.C.Yen and V.T.Chow, University of Illinois, Urbana, IL | NTIS<br>PB 253 410 |
| 140a. | WPD 03-76-04 | *Proceedings Urban Stormwater Management Seminars: Atlanta, GA, Nov. 4-6, and Denver, CO, Dec. 2-4, 1975, Edited by Dennis Athayde, USEPA, Water Planning Div., Washington, DC | NTIS<br>PB 260 889 |
| 141. | EPA-600/2-76-175a | *Assessment of Mathematical Models for Storm and Combined Sewer Management: by A.Brandstetter, Battelle, Pacific Northwest Lab., Richland, WA | NTIS<br>PB 259 597 |
| 142. | EPA-600/2-76-175b | Assessment of Mathematical Models for Storm and Combined Sewer Management-Appendix: by A.Brandstetter, Battelle, Pacific Northwest Lab., Richland, WA | NTIS ONLY<br>PB 258 644 |
| 143. | EPA-600/2-76-217a | Urban Runoff Characteristics-Vol. I, Analytical Studies: by H.C.Preul and C.N.Papadakis, University of Cincinnati, Cincinnati, OH | NTIS ONLY<br>PB 258 033 |
| 144. | EPA-600/2-76-217b | Urban Runoff Characteristics-Vol. II, by H.C.Preul and C.N.Papadakis, University of Cincinnati, Cincinnati, OH | NTIS ONLY<br>PB 258 034 |
| 145. | EPA-600/2-76-145 | *Methodology for the Study of Urban Storm Generated Pollution and Control: by Envirex, Environmental Sciences Division, Milwaukee, WI | NTIS<br>PB 258 743 |

*Copies may be obtained from EPA Storm and Combined Sewer Section, Edison, NJ 08817

| Ref. No. | Report Number | Title/Author | Source |
|---|---|---|---|
| 146. | EPA-600/2-76-222a | *Wastewater Management Program, Jamaica Bay-Vol.I, Summary Report: by D.L.Feurstein and W.O.Maddaus, City of New York, NY | NTIS<br>PB 260 887 |
| 147. | EPA-600/2-76-222b | Wastewater Management Program, Jamaica Bay-Vol. II, Supplemental Data, NYC Spring Creek: by D.L. Feurerstein and W.O.Maddaus, City of New York, NY | NTIS ONLY<br>PB 258 308 |
| 148. | EPA-600/2-76-218 | *Development and Application of a Simplified Stormwater Management Model: by Metcalf & Eddy, Inc. Palo Alto, CA | NTIS<br>PB 258 074 |
| 149. | EPA-600/2-76-244 | *Proceedings of Workshop on Microorganism in Urban Stormwater: March 24, 1975, Storm and Combined Sewer Section, USEPA, Edison, NJ | NTIS<br>Pending |
| 150. | EPA-600/2-76-243 | *Wastewater Flow Measurement in Sewers Using Ultrasound, Milwaukee: by R.J.Anderson and S.S.Bell, City of Milwaukee, WI | NTIS<br>Pending |
| 151. | EPA-600/2-76-271 | *The Swirl Concentrator for Erosion Runoff Treatment: by R.H.Sullivan, et al., American Public Works Assoc., Chicago, IL | NTIS<br>Pending |
| 152. | EPA-600/2-76-242 | *Development of a Hydrophobic Substance to Mitigate Pavement Ice Adhesion: by B.H.Alborn and H.C.Poehlmann, Ball Bros., Inc., Boulder, CO | NTIS<br>Pending |
| 153. | EPA-600/2-76-275 | *Storm Water Management Model Level I Preliminary Screening Procedures: by J.P.Heaney, et al., University of Florida, Gainesville, FL | NTIS<br>PB 259 916 |
| 154. | EPA-600/2-76-272 | *Demonstration of Void Space Storage with Treatment and Flow Regulation: by Karl R. Rohrer Assocs., Inc., Akron, OH | NTIS<br>Pending |

*Copies may be obtained from EPA Storm and Combined Sewer Section, Edison, NJ 08817

| Ref. No. | Report Number | Title/Author | Source |
|---|---|---|---|
| 155. | EPA-600/2-76-228 | Demonstration of Interim Techniques for Reclamation of Polluted Beachwater: by J.F.Weber, City of Cleveland, OH | NTIS ONLY<br>PB 258 192 |
| 156. | EPA-600/2-76-286 | *Cost Estimating Manual--Combined Sewer Overflow Storage Treatment: by H.H.Benjes, Jr., Culp, Wesner, Culp, Inc., El Dorado Hills, CA | NTIS<br>Pending |
| 157. | | Nationwide Evaluation of Combined Sewer Overflows and Urban Stormwater Discharges, Vol. II: Cost Assessment and Impacts: by J.F.Heaney, et al., University of Florida, Gainesville, FL | At Printers |
| 158. | | Field Prototype Demonstration of the Swirl Degritter: by R.H.Sullivan, et al., American Public Works Assoc., Chicago, IL | DRAFT |
| 159. | | *Handling and Disposal of Sludges from Combined Sewer Overflow Treatment-Phase I (Characterization): by M.K. Gupta, et al., Envirex, Environmental Science Division, Milwaukee, WI | At Printers |
| 160. | | Microorganisms in Urban Stormwater: by V.P.Olivieri, et al., The Johns Hopkins University, Baltimore, MD | DRAFT |
| 161. | | Assessment of the Impact of the Handling and Disposal of Sludges Arising from Combined Sewer Overflow Treatment: by M.J.Clark and A.Geinopolos, Envirex, Environmental Sciences Division, Milwaukee, WI | DRAFT |
| 162. | | Swirl Device for Regulating and Treating Combined Sewer Overflows, EPA Technology Transfer Capsule Report: by R.Field and H.E.Masters, USEPA, Storm and Combined Sewer Sec., Edison, NJ | At Printers |

*Copies may be obtained from EPA Storm and Combined Sewer Section, Edison, NJ 08817

| Ref. No. | Report Number | Title/Author | Source |
|---|---|---|---|
| 163. | EPA-600/2-77-033 | Methods for Separation of Sediment from Storm Water at Construction Sites: by J.F.Ripken, et al., Univ. of Minnesota, Minneapolis, MN | NTIS ONLY Pending |
| 164. | | Nationwide Evaluation of Combined Sewer Overflows and Urban Stormwater Discharges, Vol. III: Characterization: by R.H.Sullivan, et al., American Public Works Assoc., Chicago, IL | DRAFT |
| 165. | | Cost-Effective Pollution Control of Combined Wastes and Urban Runoff: by Clinton Bogert Assocs., Fort Lee, NJ | DRAFT |
| 166. | | Analysis of Practices for Preparing an Economic Analysis and Determining Infiltration and Inflow: Vol. II: Manual of Practice, Sewer System Evaluation Rehabilitation and New Construction: by R.H.Sullivan, et al., American Public Works Assoc., Chicago, IL | DRAFT |
| 167. | EPA-440/9-75-001 | Report on State Sediment Control Institutes Program: USEPA, Office of Water Planning and Standards | NTIS<br>PB 241 088 |
| 168. | EPA-600/8-76-001a | Erosion and Sediment Control Audio-Visual Training Program: Instruction Manual: by The State of Maryland Water Resources Administration; Dept. of Transportation, The Federal Highway Administration; The U.S. Department of Agriculture, Soil Conservation Service; and USEPA, Office of Research and Development | NTIS<br>PB 256 901 |
| 169. | EPA-600/8-76-001b | Erosion and Sediment Control Audio-visual Training Program: Workbook: by The State of Maryland Water Resources Administration; Department of Transportation, The Federal Highway Administration; The U.S. Department of Agriculture, Soil Conservation Service; and USEPA, Office of Research and Development | NTIS<br>PB 258 471 |

| Ref. No. | Report Number | Title/Author | Source |
|---|---|---|---|
| 170. | EPA-600/2-77-015 | *Treatment of Combined Sewer Overflows by High Gradient Magnetic Separation: by John Oberteuffer, et al., Sala Magnetics, Cambridge, MA | NTIS<br>Pending |
| 171. | | Cottage Farm Combined Sewer Detention and Chlorination Station, Cambridge, MA: by Commonwealth of MA Metropolitan District Commission, Boston, MA | NTIS ONLY<br>Pending |
| 172. | | Bachman Treatment Facility for Excessive Storm Flow in Sanitary Sewers: by H.W.Wolf, Texas A&M University, for Dallas Water Utilities, Dallas, TX | NTIS ONLY<br>Pending |
| 173. | | Evaluation of Fluidic Combined Sewer Regulators Under Municipal Service Conditions: by P.A.Freeman, Peter A. Freeman Assoc., Inc., Berlin, MD | At Printers |
| 174. | | Catchbasin Technology Overview and Assessment: by J.J.Lager, et al., Metcalf & Eddy, Inc., Palo Alto, CA, in association with Hydro-Research-Science, Santa Clara, CA | At Printers |

## ONGOING URBAN RUNOFF POLLUTION CONTROL PROJECTS

| Project Reference Number | On-Going Projects |
|---|---|
| P-1 | "Nationwide Characterization, Impacts, and Critical Evaluation of Combined Sewer Overflow, Stormwater, and Non-Sewered Urban Runoff." American Public Works Association, 68-03-0283 |
| P-2 | "Disinfection/Treatment of Combined Sewer Overflows - Syracuse, N.Y." Onondaga County, N.Y., 802400 |
| P-3 | "Development of a Swirl Concentrator and a Helical Combined Sewer Overflow Dual Functioning Regulator-Separator." American Public Works Association, 68-03-0272 |
| P-4 | "Demonstration of a Swirl Regulator/Solids Separator System for Control of Combined Sewer Overflows." City of Lancaster, Pennsylvania, 802219 |
| P-5 | "State-of-the-Art Update on Storm and Combined Sewer Overflow Management and Treatment, and An Urban Planning Guide for the Assessment of Storm Flow Pollution and the Selection of System Pollution Control Methods." Metcalf & Eddy, Inc., 68-03-2228 |
| P-6 | "Use of Polymers to Reduce or Eliminate Sewer Overflows in the Bachman Creek Sewer." City of Dallas, Texas, 11022 DZU |
| P-7 | "Combined Sewer Fluidic Regulator Demonstration." City of Philadelphia, 11022 FWR |
| P-8 | "Development of a Flocculation-Flotation Module." Hercules, Inc., 14-12-855 |
| P-9 | "Stormwater Treatment Facilities." City of Dallas, Texas, 11023 FAW |
| P-10 | "The Lawrence Avenue Underflow Sewer System." City of Chicago 11022 EMD |

Note: Number appearing in left margin corresponds to reference numbers cited in report text.

| Project Reference Number | On-Going Projects |
|---|---|
| P-11 | "Microorganisms in Stormwater." John Hopkins University, 802709 |
| P-12 | "Nutrient Removal Using Existing Combined Sewer Overflow Treatment Facilities." Onondaga County, N.Y., 802400 |
| P-13 | "Comparison of Alternate Sewer Design." City of Elizabeth New Jersey, 802971 |
| P-14 | a) "Refine/Verify a Simplified Model to Handle Large Areas with Minimal Data Input as a Planning Aid." Rochester Pure Water Agency, Y-005141 |
| P-15 | b) "Combined Sewer Overflow Abatement Program - Rochester, N.Y." Rochester Pure Water Agency, Y-005141 |
| P-16 | "Maximum Utilization of Water Resources in a Planned Community." Rice University, 802433 |
| P-17 | "Evaluation of Present Catch Basin Technology and Demonstration and Evaluation of New Upstream Attenuator/Solids Separator Design." Metcalf & Eddy, Inc., 68-03-0274 |
| P-18 | "Analysis of Practices for Preparing an Economic Analysis and Determining Infiltration." American Public Works Association, 803151 |
| P-19 | "Engineering Aspects of Storm and Combined Sewer Overflow Technology A Manual of Instruction." North Carolina State University, 801358 |
| P-20 | "Develop a Movie on Nature/Impacts of Stormwater Pollution As Compared to Other Forms of Water Pollution." (SRO ID No. 61ABR), EPA, Technology Transfer |
| P-21 | "Characterization and Disposal of Combined Sewer Overflow Sludges and Solids." Envirex, 69-03-0242 |
| P-22 | "Development and Demonstration of Combined Sewage Treatment Utilizing Screening and Spilt-Air Flotation." City of Milwaukee (Hawley Road) 11020 FDC |
| P-23 | "Demonstration of Screening/Dissolved-Air Flotation as an Alternative to Combined Sewer Separation." City of Racine, Wisconsin, 11023 FWS |

| Project Reference Number | On-Going Projects |
|---|---|
| P-24 | "Sludge Treatment and Disposal Methods for Combined Sewer Overflow." Envirex, 68-03-0242 |
| P-25 | "Demonstration Real-Time Automatic Control in Combined Sewer System." City and County of San Francisco, California, 803743 |
| P-28 | "Evaluation of Stormwater Treatment Methods." Minnehaha Creek Watershed District, 802535 |
| P-29 | "Evaluation and Technology Transfer of the Swirl Concentrator Principle." American Public Works Association, 803157 |
| P-30 | "Demonstration/Evaluation of Impregnated Concrete Pipe and Other Methods of Infiltration Control." Texas Water Quality Board, 802651 |
| P-31 | "Trenchless Sewer Construction and Sewer Design Innovation." Sussex County Council, Delaware, 800690 |
| P-32 | "The Somerville Marginal Conduit Including Pretreatment Facilities." Boston Metropolitan District Commission, 11023 DME |
| P-34 | "Large Scale Demonstration of Treatment of Storm-Caused Overflows by the Screening Method." City of Fort Wayne, Indiana, 11020 GYU |
| P-37 | "Boston University Bridge Storm Water Detention and Chlorination Station." Boston Metropolitan District Commission, 11023 FAT |
| P-39 | "Ultra-High Rate Filtration of Combined Sewer Overflow and Raw Dry Weather Sewage at Newtown Creek Sewage Treatment Plant." City of New York, 803271 |
| P-40 | "East Chicago Treatment Lagoon." East Chicago Sanitary District, 11020 FAV |
| P-41 | "Evaluation of Various Aspects of an Aluminum Storm Sewer System." City of LaSalle, Illinois, 11032 DTI |
| P-42 | "Pilot Plant Studies to Determine the Feasibility of Using High Gradient Magnetic Separation (HGMS) for Treating Combined Sewer Overflows." Sala Magnetics, Inc., 68-03-2218 |
| P-45 | "Development of Electromagnetic Flowmeter for Combined Sewer." Cushing Engineering, Inc., 68-03-0341 |

| Project Reference Number | On-Going Projects |
|---|---|
| P-46 | "Efficiency of Off-Stream Detention-Retention Measures as Sediment Control Devices." Howard University, 803066 |
| P-49 | "Collect and Define Availability of Test Data (Rainfall/Runoff) For Urban Models-Data Base." University of Florida, 68-03-0496 |
| P-50 | "Develop and Demonstrate New and Improved Model for Design of Combined Sewers to Prevent Solids Sedimentation and to Optimize Construction Cost." Water Resources Engineers, Inc., 68-03-2205 |
| P-51 | "Short Course on Application of Stormwater Management Models-1975." University of Massachusetts, 803069 |
| P-53 | "A Guide for Comprehensive Planning for Control of Urban Storm and Combined Sewer Runoff." University of Florida, 802411 |
| P-68 | "Verification of Water Quality Impact from CSO using Real-Time Data." County of Milwaukee, 804518 |
| P-70 | "Optimization and Testing of Highway Materials to Mitigate Ice Adhesion." Washington State University, 804660 |
| P-71 | "Evaluation and Technology Transfer of the Swirl Concentrator Principal." American Public Works Association, 803157 |
| P-66 | "Characterization of Solids Behavior in, and Variability Testing of Selected Control Techniques for Combined Sewer Systems." Northeastern University, 804578 |
| P-67 | "Demonstration of Non-Point Pollution Abatement through Improved Street Cleaning Practices." San Jose, California, 804432 |
| P-72 | "Demonstration of Erosion and Sediment Control Technology." State of California, 803181 |
| P-73 | "Methods of Separation of Sediment From Storm Water at Construction Sites." University of Minnesota, 803579 |
| P-74 | "Demonstration and Evaluation of Sediment and Erosion Control Techniques Applicable to the S.E. Piedmont, Fairfield County, South Carolina." University of South Carolina, 803724 |

## OTHER URBAN RUNOFF POLLUTION CONTROL PROGRAM REFERENCES

| Ref. No. | References |
|---|---|
| R-1 | Total Urban Pollutant Load: Sources and Abatement Strategies: Enviro Control, Inc., for Council of Environmental Quality, Draft Report, October 1973. |
| R-2 | Sources of Metals in New York City Wastewater: Larry A. Klein, et al, JWPCF, Vol. 46, No. 12, December 1974. |
| R-3 | Water Quality Effects From Urban Runoff: Robert E. Pitt and Richard Field, Preprint, 1974 American Water Works Association Conference, Boston, Massachusetts. |
| R-4 | 1974 Survey of Needs for Municipal Wastewater Treatment Facilities: USEPA, Office of Water and Hazardous Materials, Washington, D.C. |
| R-5 | Report to National Commission on Water Quality on Assessment of Technologies and Costs for Publicly owned Treatment Works under Public Law 92-500, Volume 1: Metcalf & Eddy, Inc., September 1975. |
| R-6 | Study and Assessment of the Capabilities and Cost of Technology for Control of Pollutant Discharges from Urban Runoff: Black, Crow & Eidness, Inc. and Jordan, Jones & Goulding, Inc., for the National Commission on Water Quality, Draft Report, July 1975. |
| R-6a | Management and Control of Combined Sewer Overflows: Richard Field and E.J. Struzeski, Journal Water Poll. Control Fed., Vol. 44, No. 6, July 1972, pp 1393-1415. |
| R-6b | Combined Sewer Overflows: Richard Field, Civil Engineering - ASCE Magazine, February 1973, pp 57-60. |
| R-6c | Coping with Urban Runoff in The United States: Richard Field, Water Research, Vol. 9, Pergamon Press 1975, pp 499-505. |
| R-6d | Urban Runoff Pollution Control - State of The Art: Richard Field and John A. Lager, Journal of the Environmental Engineering Division, ASCE, Vol. 101, No. EE1, Proc. Paper 11129, February 1975, pp 107-125. |

Note: Number appearing in left margin corresponds to reference numbers cited in report text.

## OTHER URBAN RUNOFF POLLUTION CONTROL PROGRAM REFERENCES (continued)

| Ref. No. | References |
|---|---|
| R-6e | Urban Runoff Must Be Controlled: Richard Field, Baltimore Engineer Magazine, March 1975. |
| R-6f | Literature Review - Urban Runoff and Combined Sewer Overflow: Richard Field and Pauline Weigel, Journal Water Pollution Control Federation, Vol. 45, No. 6, June 1973, pp 1108-1115. |
| R-6g | Literature Review - Urban Runoff and Combined Sewer Overflow: Richard Field and Pamela Szeeley, Journal Water Pollution Control Federation, Vol. 46, No. 6, June 1974, pp 1209-1226. |
| R-6h | Literature Review - Urban Runoff and Combined Sewer Overflow: Richard Field and Donna Knowles, Journal Water Pollution Control Federation, Vol. 47, No. 6, June 1975, pp 1353-1369. |
| R-6i | Literature Review - Urban Runoff and Combined Sewer Overflow: Richard Field, J. Curtis, and R. Bowden, Journal Water Pollution Control Federation, Vol. 48, No. 6, June 1976, pp 1191-1206. |
| R-7 | Stormwater Pollution Control: A New Technology: Richard Field and Anthony N. Tafuri, 28 Minute - 16 mm - Sound - Color Film, Available from: General Services Administration, National Archives and Records Service, National Audiovisual Center, Washington, D.C. 20409, Rental - $12.50, Purchase - $119.50. |
| R-8 | Areawide Assessment Procedures Manual: Hydroscience, Inc., USEPA, Chapters 2 & 3, and Appendix I, Cincinnati, OH, September 1976. |
| R-9 | Generalized Computer Program, Urban Storm Water Runoff, STORM: Hydrologic Engineering Center for U.S. Army, Corps of Engineers, 723-S8-L2520, October 1974. |
| R-10 | A Model for Evaluating Runoff-Quality in Metropolitan Master Planning: L.A. Roesner, *et al*, Water Resources Engineers, A.D. Feldman, The Hydrologic Engineering Center, for U.S. Army, Corps of Engineers, A.O. Friedland, Department of Public Works, City of San Francisco, Technical Memorandum No. 23, ASCE, April 1974. |

## OTHER URBAN RUNOFF POLLUTION CONTROL PROGRAM REFERENCES (continued)

| Ref. No. | References |
|---|---|
| R-11 | Water Pollution and Associated Effects From Street Salting: Richard Field, Edmond J. Struzeski, Jr., Hugh Masters, Anthony Tafuri, Journal of the Environmental Engineering Division, ASCE, Vol. 100, No. EE2, Proc. Paper 10473, April 1974, pp 459-477. |
| R-12 | Community Action Guideline for Soil Erosion and Sediment Control: National Association of Counties Research Foundation, March 1970. |
| R-13 | Standards and Specifications for Soil Erosion and Sediment Control in Developing Areas: The United States Department of Agriculture, Soil Conservation Service for The State of Maryland, June 1975. |
| R-14 | Infiltration - Inflow Analysis: David J. Cesareo and Richard Field, Journal of The Environmental Engineering Division, ASCE, Vol. 101, No. EE5, Proc. Paper 11645, October 1975, pp 775-785. |
| R-15 | Design of a Combined Sewer Overflow Regulator/Concentrator: Richard Field, Journal Water Pollution Control Federation, Vol. 46, No. 7, July 1974, pp 1722-1741. |
| R-16 | Give Stormwater Pollutants the Spin: Richard Field, et al, The American City & Country Magazine, April 1976, pp 77-78. |